



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Dual role of pericyte 61-integrin in tumour blood vessels

Citation for published version:

Reynolds, LE, D'amico, G, Lechertier, T, Papachristodoulou, A, Muñoz-félix, JM, De Arcangelis, A, Baker, M, Serrels, B & Hodivala-dilke, KM 2017, 'Dual role of pericyte 61-integrin in tumour blood vessels' *Journal of Cell Science*, pp. jcs.197848. DOI: 10.1242/jcs.197848

Digital Object Identifier (DOI):

[10.1242/jcs.197848](https://doi.org/10.1242/jcs.197848)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Journal of Cell Science

Publisher Rights Statement:

This is the authors final peer-reviewed manuscript as accepted for publication.

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Dual role of pericyte $\alpha6\beta1$ -integrin in tumour blood vessels

Louise E. Reynolds^{1?}, Gabriela D'Amico^{1*}, Tanguy Lechertier^{1*}, Alexandros

Papachristodoulou², José M. Muñoz-Félix¹, Adèle De Arcangelis³, Marianne Baker¹,

Bryan Serrels⁴ and Kairbaan M. Hodivala-Dilke¹

¹Adhesion and Angiogenesis Laboratory, Centre for Tumour Biology,
Barts Cancer Institute- A CRUK Centre of Excellence,
Queen Mary University of London,
Charterhouse Square,
London, UK.
EC1M 6BQ.

²Laboratory for Molecular Neuro-Oncology,
Dept. of Neurology,
University Hospital Zurich,
Frauenklinikstrasse 26,
CH-8091 Zurich,
Switzerland.

³IGBMC
UMR 7104, INSERM U964, Université de Strasbourg,
BP. 10142,
1, Rue Laurent Fries,
67404 Illkirch Cedex,
France.

⁴Cancer Research UK Edinburgh Centre,
University of Edinburgh,
Crewe Road South,
Edinburgh, UK.
EH4 2XR.

*These authors contributed equally

[?]Corresponding author: l.reynolds@qmul.ac.uk

Running title: Dual role for pericyte $\alpha6\beta1$ in tumours

Abstract

The integrin $\alpha 6\beta 1$ is a major laminin receptor, and formation of a laminin-rich basement membrane is a key feature in tumour blood vessel stabilisation and pericyte recruitment; processes that are important in the growth and maturation of tumour blood vessels. However, the role of pericyte $\alpha 6\beta 1$ -integrin in angiogenesis is largely unknown. We developed mice where the $\alpha 6$ -integrin subunit is deleted in pericytes and examined tumour angiogenesis and growth. These mice had: i) reduced pericyte coverage of tumour blood vessels; ii) reduced tumour blood vessel stability; iii) increased blood vessel diameter; iv) enhanced leakiness and, v) abnormal blood vessel basement membrane architecture. Surprisingly, tumour growth, blood vessel density and metastasis were not altered. Analysis of retinas revealed that deletion of pericyte $\alpha 6$ -integrin did not affect physiological angiogenesis. At the molecular level, we provide evidence that pericyte $\alpha 6$ -integrin controls PDGFR β expression and AKT/mTOR signalling. Together, we show that pericyte $\alpha 6\beta 1$ -integrin regulates tumour blood vessels by both controlling PDGFR β and basement membrane architecture. These data establish a novel dual role for pericyte $\alpha 6$ -integrin that affects the blood vessel phenotype during pathological angiogenesis.

Key words

Integrins; pericyte; tumour growth; angiogenesis

Introduction

Blood vessels comprise of endothelial cells supported by mural cells, also known as pericytes. Although the role of integrins in endothelial biology has been studied extensively (Avraamides et al., 2008, Germain et al., 2010), almost nothing is known about the role of pericyte integrins, including $\alpha 6$ -integrin (Garmy-Susini et al., 2005, Liu and Leask, 2012). Integrins are transmembrane cell surface receptors that mediate cell-cell and cell-extracellular matrix (ECM) interactions. One of the major components of the vascular basement membrane is laminin whose predominant adhesive receptors include integrins $\alpha 6\beta 1$ and $\alpha 6\beta 4$ (Durbeej, 2010). Targeting endothelial integrins has proved to be relatively beneficial in treating cancer in preclinical studies (Yamada et al., 2006, Tabatabai et al., 2010) but has had limited success in clinical trials (Patel et al., 2001), therefore new targets, including pericytes are currently being examined.

Tumour blood vessels have many structural abnormalities including decreased endothelial barrier function, reduced pericyte recruitment and poor basement membrane organisation when compared with normal, quiescent vessels (Armulik et al., 2005). Studies have shown that pericyte recruitment and investment to blood vessels stimulates endothelial cell basement membrane (BM) deposition and organisation *in vitro* (Stratman et al., 2009). This is mediated mainly by secretion of endothelial PDGF-BB, attracting PDGFR β -positive pericytes which adhere to the BM surrounding endothelial cells (Stratman et al., 2010, Abramsson et al., 2003). *In vivo*, mice lacking PDGF-BB/PDGFR β signalling fail to adequately recruit pericytes to newly formed blood vessels resulting in severe perturbation of blood vessel stabilisation and maturation (Hellberg et al., 2010). Furthermore, interference with PDGF-BB/PDGFR β signalling results in disruption of already established endothelial/pericyte associations and vessel destabilisation during retinal development (Benjamin et al., 1998). Whether pericyte $\alpha 6$ -integrin might regulate tumour vessel stability was hitherto unknown.

In the present study, we examined the role of pericyte $\alpha 6$ -integrin on tumour blood vessel function using a genetic ablation approach. Surprisingly, loss of pericyte $\alpha 6$ -integrin did not affect tumour growth, angiogenesis or metastasis but did cause a decrease in pericyte association with tumour blood vessels and poor basement membrane organisation, with an associated increase in vessel leakage and instability. At the molecular level, we demonstrate a novel mechanism by which pericyte $\alpha 6$ -integrin reduces PDGFR β expression on pericytes and therefore diminishes responses to PDGF-BB. This, in turn, is the likely mechanism for aberrant pericyte investment of tumour blood vessels. Together, our data suggest that pericyte $\alpha 6\beta 1$ -integrin plays a dual role in regulating PDGFR β expression and BM organisation that likely increases vessel leakage and instability.

Methods

Generation of mice

$\alpha 6$ -integrin floxed mice (Bouvard et al., 2012, Germain et al., 2010) were bred with mice expressing Cre-recombinase under the control of the Platelet Derived Growth Factor Receptor β (PDGFR β) promoter, PDGFR β Cre (Foo et al., 2006) to generate *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice. mTmG mice were obtained from Cancer Research UK.

Immunostaining of tumour sections

Unless otherwise stated, frozen sections were fixed in ice-cold acetone for 10 min followed by permeabilisation with 0.5% NP-40 for 10 min. Sections were blocked for 45 min with 1.0% bovine serum albumin (BSA) and 0.1% Tween 20 in PBS. Primary antibodies were incubated overnight at 4°C followed by incubation with a fluorescently conjugated secondary antibody for 1 h at room temperature (1:1000; Invitrogen). The following primary antibodies were used: $\alpha 6$ -integrin (Chemicon GoH3), NG2 (Millipore AB5320), endomucin (Santa Cruz) (all 1:100).

Quantitation of $\alpha 6$ -integrin on pericytes

Quantification of $\alpha 6$ -integrin expression on NG2-positive pericytes on tumour blood vessels from *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice was performed using ImageJ™ software. The mean pixel intensity of $\alpha 6$ -integrin expression on NG2-positive pericytes was quantitated.

Immunostaining and quantitation of basement membrane

Immunostaining for laminin $\alpha 4$ chain (kind gift from Takako Sasaki) was performed as described previously (Sasaki et al., 2001). For laminin $\alpha 5$ chain, sections were fixed in 4% paraformaldehyde (PFA), washed twice with PBS, then blocked with 1% BSA for 30 min. Sections were incubated overnight at 4°C with primary antibody (1:400 dilution in blocking buffer) (kind gift from Jeffrey H. Miner (Pierce et al., 2000)), followed by several washes,

incubation with Alexa 488-conjugated anti-rabbit secondary antibody (1:1000; Invitrogen) and mounted.

For Collagen IV (Abcam) and Fibronectin (Abcam) staining, sections were fixed in 4% PFA, blocked with 3% NGS, 0.1% TritonX-100 (TX-100) in PBS for 30 min at room temperature. Primary antibody was diluted 1:200 in 1% normal goat serum (NGS), 0.1% TX-100 in PBS and incubated overnight at 4°C. Sections were washed three times with PBS, incubated with Alexa 488-conjugated anti-rabbit secondary antibody (Invitrogen) diluted 1:100 in 1% NGS TX-100, washed three times and mounted with Prolong Gold anti-fade with DAPI.

Fluorescence staining was visualised using the Axioplan microscope (Zeiss). Images were captured using Axiovision Rel. 4.0 software. The Axiovision software linear measuring tool was used to analyse the spread (in μm) of basement membrane surrounding blood vessels.

Pericyte association

For analysis of pericyte coverage, tumour sections were double immunostained for endomucin and NG2 (for details see Immunostaining of tumour sections). Pericyte coverage was quantified by counting the total number of endomucin positive blood vessels across whole tumour sections followed by the numbers of blood vessels positive for both endomucin and NG2. The percentage (%) of blood vessels with associated pericytes was calculated.

Tumour blood vessel leakage

To analyse tumour blood vessel leakage, Hoechst dye (4 $\mu\text{g}/\text{ml}$; Sigma, H33258) was used. Hoechst dyes diffuse quickly from vessels and binds to the DNA of cells surrounding blood vessels, allowing for quantitation of areas of uptake by perivascular tumour cells and hence blood vessel leakage (Janssen et al., 2005). Briefly, mice were injected sequentially with 100 μl PE-CD31 (Biolegend; to stain functional blood vessels) followed 9 min later with 100 μl Hoechst (4 $\mu\text{g}/\text{ml}$; Sigma, H33258) via the tail vein and 1 min later culled. Tumours were excised and snap frozen. 8-10 fields at x20 magnification were analysed by ImageJ™. For

quantitation, blood vessel leakage was calculated by counting the numbers of Hoechst positive nuclei surrounding PE-CD31 positive tumour areas. Results are shown in arbitrary units (AU).

Tumour growth and angiogenesis

The syngeneic mouse tumour cell lines B16F0 (melanoma, derived from C57BL6) and Lewis Lung Carcinoma (LLC) (both from ATCC) were used in subcutaneous tumour growth experiments. 1×10^6 B16F0 cells or 0.5×10^6 LLC cells, resuspended in 100 μ l of phosphate buffered saline (PBS), were injected subcutaneously into the flank of 12-14 week old *pdgfr β cre⁺; α 6fl/fl* and littermate control mice (*pdgfr β cre⁻; α 6fl/fl* mice). Tumour growth was measured every 2 days using calipers. After 14 days, animals were culled, tumours excised and either fixed in 4% formaldehyde in PBS overnight, or snap-frozen in liquid nitrogen, for subsequent immunohistochemical analysis.

Blood vessel density

Size-matched tumours from *pdgfr β cre⁻; α 6fl/fl* and *pdgfr β cre⁺; α 6fl/fl* mice were snap-frozen and bisected, and cryosections made. Frozen sections were fixed in 100% acetone at -20°C , rehydrated in PBS for 10 min, and then blocked (PBS, 1% BSA, 0.1% Tween-20) for 45 min at room temperature. After a 5 min wash in PBS, sections were incubated with 1:100 anti-endomucin in blocking buffer for 45 min at room temperature. After three 5 min washes in PBS, sections were incubated with Alexa 488-anti-rat secondary antibody (Invitrogen) diluted in blocking buffer. After three 5 min washes in PBS, sections were washed briefly with distilled water before being mounted. The number of endomucin-positive blood vessels present across the entire area of each mid-line tumour section from size and age-matched tumours was counted and divided by the area of the section to determine tumour blood vessel density.

Tumour blood vessel diameter

The diameter of endomucin-positive blood vessels were quantified using the Axiovision™ software linear measuring tool.

Perfused blood vessel analysis

For analysis of the % of perfused, functional tumour vessels, 100 µl PE-CD31 antibody (Biolegend, London, UK) was injected via the tail vein 10 minutes (mins) prior to culling mice. Tumours were dissected immediately, snap frozen and sectioned. Frozen sections were then immunostained for endomucin as described above. To calculate the % number of functional vessels, the number of PE-CD31-positive blood vessels was divided by the total number of endomucin-positive blood vessels.

Tumour metastasis

0.5 x 10⁶ LLC tumour cells were injected subcutaneously and tumours were allowed to reach a size of 100 mm³ before surgical resection. The mice were monitored for up to 3 weeks, after which the metastatic burden quantified by counting numbers of surface lung metastases. Lungs were then fixed and sections stained with H&E for further analysis. The numbers of surface metastases was counted immediately after fixation, to give the total number of lung metastases per mouse. To examine internal metastases, H&E stained sections were analysed and the area of individual metastases was measured using Axiovision™ software, to give the internal metastatic nodule area.

Primary endothelial cell, fibroblast and pericyte isolation

Primary mouse endothelial cells were isolated from lungs and maintained as described previously (Reynolds and Hodivala-Dilke, 2006). Briefly, *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mouse lungs were minced, collagenase digested (Type I, Gibco), strained through a 70 µm cell strainer (BD Falcon) and the resulting cell suspension plated on flasks

coated with a mixture of 0.1% gelatin (Sigma), 10µg/ml fibronectin (Millipore) and 30µg/ml rat tail collagen (Sigma). Endothelial cells were purified by a single negative (FCγ sort-RII/III; Pharmingen) and two positive cell sorts (ICAM-2; Pharmingen), using anti-rat IgG-conjugated magnetic beads (Dyna). During preparation of primary endothelial cells, lung fibroblasts were isolated from the non-endothelial cell population that was generated during the first positive sort. For all cell types, passaging occurred when cells reached 70% confluency. Cells were trypsinised, centrifuged, washed with PBS and replated on pre-coated flasks for endothelial cells and pericytes and non-coated flasks for fibroblasts. Fibroblasts were cultured in DMEM + 10% FCS to passage 4, Endothelial cells in MLEC (Ham's F-12, DMEM (low glucose), 10% FCS, heparin and endothelial mitogen (Generon)) to passage 4-5. Pericytes were isolated from mouse brains as described previously (Tigges et al., 2012) and cultured in Pericyte medium (ScienCell) to passage 9.

FACS analysis

Primary mouse brain pericytes isolated from *pdgfrβcre-;α6fl/fl* and *pdgfrβcre+;α6fl/fl* mice were incubated with an anti-α6-integrin subunit antibody (GoH3; Abcam) to determine expression levels, for 30 min at 4°C. This was followed by incubation, for 30 min at 4°C with an appropriate FITC-conjugated secondary antibody. Unstained cells were used as a control. For characterisation of primary mouse brain pericytes, cells were washed with PBS and trypsinised at 37°C. The cell suspensions were washed in medium containing serum and centrifuged at 1, 200 rpm for 3 min. Cells were washed with cold FACS buffer (1% BSA/PBS) and fixed with 4% formaldehyde for 10 min at room temp. Cells were washed with FACS buffer and the cell suspensions were incubated with the following primary antibodies: PE-anti CD31 (Biolegend), PE-anti Mac1 (CD11b) (Biolegend), PE-anti GFAP (BD Biosciences), APC-anti PDGFRβ (Biolegend), PE-Cy7-anti CD146 (Biolegend) for 30 min. Cells were then washed three times in sample buffer and resuspended in a final volume

of 400 ml. As a control, unstained cells were FACS sorted. Primary mouse lung endothelial cells were incubated with PE-anti CD31 (Biolegend).

Western blot analysis

Primary lung endothelial cells, lung fibroblasts and brain pericytes isolated from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice were grown to 70-80% confluency then lysed in RIPA buffer. 15-30 μ g protein was run on 8% polyacrylamide gels then transferred to nitrocellulose membranes. Membranes were probed with primary antibody overnight at 4°C. All antibodies (ERK, AKT, α 6-integrin) for the signalling studies were purchased from Cell Signaling and used at a 1:1000 dilution. α 3-integrin antibody was purchased from Millipore (AB1920). The anti-HSC70 antibody, used as a loading control, was from Santa Cruz and used at 1:5000 dilution. For PDGF-BB stimulation, pericytes were serum starved for 6 h in Optimem with 0.5% FCS, then stimulated with PDGF-BB (30 ng/ml; Peprotech, UK) for 0, 30 s, 60 s, 5 min, 15 min, 30 min before lysis. Densitometric readings of band intensities were obtained using the ImageJ™ software.

PDGFR β immunostaining of cells

Immunostaining of brain pericytes, isolated from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice for PDGFR β (28E1, Cell Signaling), was performed according to the manufacturers' protocol.

Aortic ring assay

Thoracic aortas were isolated from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* 8-10 week old mice and prepared for culture as described previously (Baker et al., 2012). Where indicated, culture medium was supplemented with PDGF-BB at 30 ng/ml (Peprotech, London, UK). PBS was used as a control. Rings were fed every 3 days with fresh medium with or without

PDGF-BB (30 ng/ml). Sprouting microvessels were counted after 9 days in culture, fixed and stained to identify endothelial cells and pericytes, as described previously (Baker et al., 2012).

Scratch wound assays

Primary mouse brain pericytes from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice were grown to confluency in Pericyte medium (ScienCell, CA. Cat no. 0010) in 6-well plates coated with 0.1% gelatin and fibronectin. Cells were serum starved overnight in Optimem containing 0.5% FCS. The following day, the monolayers were scratched horizontally and vertically through the centre of each well. The cells were either stimulated with PDGF-BB (30 ng/ml) or not and cell migration monitored over a 72 h period. At each timepoint, 12 photographs were taken of each scratch and the wound width was measured using ImageJ™ software. Results were normalised to time 0.

Proliferation assay

Primary WT and α 6-null brain pericyte proliferation was assessed using the CellTiter 96® Aqueous One Solution Reagent (Promega), according to the manufacturer's instructions. Plates were read at a wavelength of 490 nm, with absorbance measured relative to blank wells containing reagent only. Plates were coated with 0.1% gelatin and fibronectin prior to seeding the pericytes.

Characterising transgenic mice

The primers for the Cre PCR were forward primer: 5-GCCGCATTACCGGTCGATGCAAGA-3; reverse primer: 5-GTGGCAGATGGCGCGGCAACACCATT-3. The reaction generates a fragment of approximately 1000 bp. The primers for α 6-floxed PCR were forward primer: 5-AGAAGGTGATGTTACCCT-3 and reverse primer: 5-AATGTAACTAGCATTCAAGT-3.

The PCR reaction generates a 154 bp fragment for the $\alpha 6$ -floxed allele and a 120 bp fragment for the wild-type allele (described in Germain *et al.*).

Whole-mount immunofluorescence on retinas

Postnatal day (P) 9 eyes were fixed in 4% PFA overnight at 4°C. Retinas were dissected in PBS and, after 5 washes in PBS, incubated in blocking solution (1% FBS (Sigma), 3% BSA (Sigma), 0.5% Triton X-100 (Sigma), 0.01% Na deoxycholate (Sigma), 0.02% Na Azide (Sigma) in PBS, pH7.4) for 2 h at room temperature. Retinas were incubated for overnight at 4°C with primary antibodies: rabbit polyclonal anti-NG2 (Millipore, #AB5320, dilution 1:500) in blocking solution:PBS (1:1) overnight at 4°C. Retinas were then washed several times in PBS and incubated with secondary antibody AlexaFluor 488 and AlexaFluor 548 conjugates (Life Technologies), all diluted 1:300, overnight at 4°C. After several washes in PBS, retinas were post-fixed in 1% PFA and re-blocked in 1%BSA/0.5% Triton X-100 in PBS for 1 hr at room temperature. After 2 rinses in PBlec (0.1 nM CaCl₂, 0.1 MgCl₂ mM, 0.1 MnCl₂ mM, and 1% Triton X-100 in PBS; pH6.8), retinas were incubated with biotinylated Isolectin B4 (B1205, VectorLabs, dilution 1:12.5) in PBlec overnight at 4°C. After several washes in PBS, retinas were incubated with Streptavidin Alexa Fluor 647 conjugate diluted 1:100 in 0.5%BSA/0.3% Triton X-100 in PBS overnight at 4°C. After several washes in PBS, retinas were incubated with Hoechst dye as a nuclear counterstain (Life Technologies), washed and mounted with ProLong Gold (Molecular Probes). Fluorescently labelled samples were imaged with a confocal microscope (Carl Zeiss LSM 710, Carl Zeiss) in multichannel mode. Three-dimensional projections were digitally reconstructed from confocal z-stacks using the LSM Zen 2009 software and Image J open source image processing software (version:2.0.0-rc-43/1.51d).

Adhesion assay

Adhesion assays were performed as previously described (Germain et al., 2010), using brain pericytes isolated from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice. Adhesion of pericytes is presented relative to adhesion of pericytes to fibronectin for the same genotype.

Immunostaining of immune cells, fibroblasts and endothelial cells

Immunostaining of immune cells from B16F0 tumour sections was performed as described previously (Reynolds et al., 2010).

Primary mouse lung fibroblasts and endothelial cells were fixed with 4% PFA for 10 min, washed twice and blocked with 5% NGS in PBS for 30 min at room temperature. Primary antibodies to vimentin (1:100; Cell Signaling), NG2 (1:100; MAB 5385, Millipore), endomucin (1:100; V7C7, Santa Cruz) and α -sma (clone 1A4, Sigma) were incubated for 1 h at room temperature, washed three times with PBS, and incubated with the relevant secondary antibody for 45 min at room temperature.

Reverse phase protein array (RPPA) Nitrocellulose slides

Cell lysates were prepared using ice cold RIPA buffer. After normalization, to adjust protein concentrations, triplicate spots of each lysate were deposited onto 16-pad Avid Nitrocellulose slides (Grace Bio) under conditions of constant 70% humidity using an Aushon 2470 Array platform (Aushon BioSystems). After printing and washing steps, the arrays were blocked by incubation in Superblock (Thermo Scientific #37535) for 10 min. The protein array chips were subsequently incubated for 1 h with primary antibody followed by repeat blocking with Superblock and 30 min incubation with anti-rabbit Dylight-800 conjugated secondary antibody (Cell Signaling, cat.no.5151).

Following secondary antibody incubation and subsequent wash steps the immune-stained arrays were imaged using an Innopsys 710IR scanner (Innopsys France). Microarray images were obtained at the highest gain without saturation of fluorescent signal detection. Image

analysis was performed using Mapix software (Innopsys France) to calculate the relative fluorescence intensity (RFI) value for each sample. An estimate of total protein printed per feature on the array was determined by staining an array slide with fastgreen protein stain. Readout values for all antibodies tested are expressed as a ratio of total protein loaded and are presented as the mean of technical replicates.

Statistical analysis

Statistical significance was calculated using Student's *t*-test. $p < 0.05$ was considered statistically significant.

Ethical regulations

All animals were used in accord with United Kingdom Home Office regulations (Home Office license number 70/7449). The in-house Ethics Committee at Queen Mary University of London has approved all experiments, using mice under the project license.

Results

Generation and characterisation of *pdgfr β cre+; α 6fl/fl* mice

We have generated a new mouse model that enables us to study deletion of α 6-integrin in pericytes. We bred α 6-integrin floxed mice (Bouvard et al., 2012, Germain et al., 2010) with mice expressing Cre-recombinase under the control of the Platelet Derived Growth Factor Receptor β (PDGFR β) promoter, PDGFR β Cre (Foo et al., 2006), to generate *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice. Mice were born to *pdgfr β cre+; α 6fl/fl* x *pdgfr β cre-; α 6fl/fl* crosses at normal Mendelian ratios and male:female ratios with no obvious adverse phenotype (**Fig. S1A-C**). Mice were genotyped by PCR analysis (**Fig. S1D**). Histological analysis of H&E-stained sections of lung, heart, liver and spleen from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* adult mice showed no apparent tissue defects (**Fig. S1E**). Furthermore, no apparent vascular abnormalities were observed in these tissues (**Fig. S1F**) or in the developing retina (**Fig. S1G**), suggesting that loss of PDGFR β -driven α 6 had no apparent effect on physiological angiogenesis. Finally, to confirm pericyte specific Cre expression in our mouse model, we crossed *pdgfr β cre-* and *pdgfr β cre+* mice with the *mTmG* reporter mouse (Muzumdar et al., 2007). Analysis of tumour blood vessels from *pdgfr β cre-; mTmG* and *pdgfr β cre+; mTmG* mice showed that although tomato (mT) expression was observed in blood vessels in both *pdgfr β cre-; mTmG* and *pdgfr β cre+; mTmG* mice, GFP (mG) expression, was present in mouse tissue only after Cre excision, and only observed in pericytes in *pdgfr β cre+; mTmG* mice (**Fig. S2A, B**). As expected, α 6-integrin is expressed on tumour endothelial cells, shown by co-expression of α 6-integrin and the endothelial cell marker CD31 (**Fig. S2C**), suggesting that the deletion of α 6-integrin *in vivo* was restricted to PDGFR β -positive pericytes.

α 6-integrin deficiency on pericytes impairs tumour blood vessel stabilisation

Very few studies have examined the role of pericyte integrins in tumour blood vessels *in vivo* (Garmy-Susini et al., 2005, Turner et al., 2014, Liu and Leask, 2012). To assess whether α 6-

integrin is required for pericyte investment on blood vessels during tumour angiogenesis, *pdgfr β cre⁻; α 6fl/fl* and *pdgfr β cre⁺; α 6fl/fl* mice were injected with either syngeneic B16F0 melanoma or LLC tumour cells. We first established loss of α 6-integrin expression in pericytes in tumour blood vessels from *pdgfr β cre⁺; α 6fl/fl* mice. Tumour sections from *pdgfr β cre⁻; α 6fl/fl* and *pdgfr β cre⁺; α 6fl/fl* were double stained for NG2 (a pericyte marker) and α 6-integrin. Although α 6-integrin was expressed in NG2 positive pericytes in tumour blood vessels in *pdgfr β cre⁻; α 6fl/fl* control mice, α 6-integrin was undetectable in pericytes from *pdgfr β cre⁺; α 6fl/fl* mice (**Fig. 1A**) confirming that α 6-integrin expression is reduced on pericytes in tumours grown in *pdgfr β cre⁺; α 6fl/fl* mice. Quantification revealed a significant reduction in α 6-integrin expression in NG2-positive pericytes in tumour blood vessels from *pdgfr β cre⁺; α 6fl/fl* mice (**Fig. 1B**). Having confirmed deletion of α 6-integrin in pericytes in tumour blood vessels from *pdgfr β cre⁺; α 6fl/fl* mice *in vivo*, we asked whether PDGFR β driven α 6-integrin deletion could affect pericyte association with tumour blood vessels. A significant reduction in the number of pericytes associated with blood vessels in B16F0 and LLC tumours grown in *pdgfr β cre⁺; α 6fl/fl* mice was observed (**Fig. 1C**). Thus, the absence of pericyte α 6-integrin corresponds with a reduction in pericyte association with blood vessels.

Blood vessel leakage is enhanced in tumours from *pdgfr β cre⁺; α 6fl/fl* mice

We next examined other possible biological consequences of the loss of pericyte α 6-integrin. We found that reduced pericyte investment correlated with a higher frequency of blood vessels with a large diameter (>100 μ m), in tumour blood vessels from *pdgfr β cre⁺; α 6fl/fl* mice (**Fig. 1D**). A known result of increased blood vessel diameter is poor functionality of blood vessels (Huang et al., 2010). We therefore examined tumour blood vessel leakage by measuring the relative level of perivascular Hoechst after intravenous injection of Hoechst dye. Blood vessel leakage was calculated by counting the numbers of Hoechst positive nuclei surrounding tumour blood vessels. Tumour blood vessels from *pdgfr β cre⁺; α 6fl/fl* mice

showed significantly more leakage of Hoechst dye than from *pdgfr β cre-; α 6fl/fl* mouse tumours (**Fig. 1E**). Together, these data demonstrate that loss of pericyte α 6-integrin is sufficient to reduce pericyte coverage of tumour blood vessels and increase vessel diameter and leakage.

Blood vessel basement membrane organisation is altered in tumours grown in *pdgfr β cre+; α 6fl/fl* mice

Given that extracellular matrix (ECM) deposition is a crucial step in the maturation of tumour blood vessels, and requires the presence of both pericytes and endothelial cells, we examined whether the distribution of various BM matrices correlated with the observed decrease in pericyte tumour blood vessel association in *pdgfr β cre+; α 6fl/fl* mice. Concomitant with reduced vascular stabilisation and increased leakiness in the *pdgfr β cre+; α 6fl/fl* tumour blood vessels, a higher frequency of disorganised BM around tumour blood vessels was seen in *pdgfr β cre+; α 6fl/fl* mice. Specifically, immunofluorescence analysis of collagen IV (**Fig. 2A**), fibronectin (**Fig. 2B**), laminins α 5- (**Fig. 2C**) and α 4-chains (**Fig. 2D**) in the BM around tumour blood vessels, revealed a “shorelining” pattern of BM components (DiPersio et al., 1997) in *pdgfr β cre+; α 6fl/fl* mice. Quantification confirmed that the BM was wider with aberrant organisation, in blood vessels from *pdgfr β cre+; α 6fl/fl* mice than from *pdgfr β cre-; α 6fl/fl* mice (**Fig. 2E**). Adhesion assays, using mouse primary pericytes showed, as expected, that the absence of α 6-integrin reduced significantly the adherence to Laminin 111 (Lm-1), but not fibronectin (**Fig. S3A**).

Since blood vessel stabilisation is a consequence not only of BM deposition but the association of supporting cells, ie. pericytes, these results show that pericyte investment and the formation of a normal BM is affected by deletion of pericyte α 6-integrin, and likely contributes to the abnormal stability and leakage of tumour blood vessels in *pdgfr β cre+; α 6fl/fl* mice.

Depletion of pericyte $\alpha 6$ -integrin does not affect tumour growth or metastasis

Despite the dramatic changes in pericyte association, vessel leakage and BM architecture, no significant difference in tumour growth (**Fig. 3A**), blood vessel density (**Fig. 3B**), numbers of functional blood vessels (**Fig. 3C**), metastasis (**Fig. 3D**) or immune cell infiltrate (**Fig. S3B**) was observed between *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice. These data suggest that the changes in blood vessels observed in *pdgfr β cre+; $\alpha 6$ fl/fl* mice is not sufficient to affect tumour growth, angiogenesis or metastasis.

$\alpha 6$ -integrin controls pericyte PDGFR β expression

In mice, genetic ablation of PDGF-BB and PDGFR β leads to various vascular abnormalities associated with pericyte loss, including a loss of pericyte association to blood vessels (Abramsson et al., 2003). Since PDGF-BB is one of the major growth factors involved in pericyte investment to blood vessels (Abramsson et al., 2003, Furuhashi et al., 2004) we sought to investigate whether loss of $\alpha 6$ -integrin affected pericyte responses to PDGF-BB. Initially, primary pericytes, fibroblasts and endothelial cells were isolated from *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice and characterised (**Fig. S4A-C**). Western blot analysis and FACS confirmed deletion of $\alpha 6$ -integrin only in pericytes (**Fig. 4A**). This loss of $\alpha 6$ -integrin was not compensated for by the overexpression of another laminin receptor, the $\alpha 3$ -integrin subunit in $\alpha 6$ -null pericytes (**Fig. 4B**). Further Western blot analysis showed that $\alpha 6$ -integrin levels were normal in fibroblasts and endothelial cells isolated from *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice (**Fig. 4C**). The loss of $\alpha 6$ -integrin in pericytes correlated with an approximately two-fold reduction in levels of PDGFR β in $\alpha 6$ -null pericytes, suggesting that $\alpha 6$ -integrin was indeed regulating the expression of PDGFR β protein (**Fig. 4D**). Additionally, PDGFR β levels were significantly reduced in PDGFR β immunostained $\alpha 6$ -null pericytes compared with WT pericytes *in vitro* (**Fig. 4E**).

PDGF-BB responses are diminished in $\alpha 6$ -null pericytes

Since changes in receptor expression levels do not always reflect changes in downstream signalling of the corresponding tyrosine kinase receptor (Platta and Stenmark, 2011), we next sought to confirm whether the decreased expression of PDGFR β correlated with diminished responses to PDGF-BB stimulation in $\alpha 6$ -null pericytes. We showed that PDGF-BB stimulated *ex vivo* microvessel sprouting was reduced in aortic rings isolated from *pdgfr β cre+; $\alpha 6$ fl/fl* mice compared with PDGF-BB stimulated sprouting from *pdgfr β cre-; $\alpha 6$ fl/fl* mouse aortic rings (**Fig. 5A**). In this assay the vessel sprouts become surrounded by pericytes which proliferate and migrate along the endothelium (Nicosia, 2009). We were unable to analyse pericyte coverage in *pdgfr β cre+; $\alpha 6$ fl/fl* aortic rings due to the complete lack of sprouts that grew in response to PDGF-BB. In response to PDGF-BB, $\alpha 6$ -null pericyte migration and proliferation was significantly reduced when compared with WT controls (**Fig. 5B, C**). We next examined the effect of $\alpha 6$ -deficiency on PDGF-BB stimulated downstream signalling in pericytes. Interaction of PDGFR β with PDGF-BB activates several signalling pathways, including MAP Kinase (ERK) and PI3K/AKT. Western blot analysis showed that, in $\alpha 6$ -null pericytes, PDGF-BB mediated stimulation of ERK and AKT pathways were both reduced significantly (**Fig. 5D, E**). Since integrins and PDGFR can activate many downstream signalling pathways, we performed a non-candidate proteomic study using Reverse Phase Protein Array (RPPA) analysis, to identify other possible pathways that may be affected by the absence of $\alpha 6$ -integrin on pericytes. We found that components of the AKT/mTOR signaling pathway (AKT, P70 S6kinase, mTOR, pS6 ribosomal protein and 4E-BP1) were significantly downregulated in $\alpha 6$ -null pericytes (**Fig. S4D**). This pathway is activated downstream of integrins and is known to be regulated by PDGFR expression and function (Zhang et al., 2007). These results suggest that absence of $\alpha 6$ -integrin results in a reduction of PDGFR β levels, significantly reducing pericyte responses to PDGF-BB.

Collectively, these results demonstrate a novel role for pericyte $\alpha 6$ -integrin in both the

regulation of PDGFR β levels that was previously unknown, and in BM organisation. This dual mechanism confers a blood vessel phenotype that affects only the primary tumour.

Discussion

The role of pericyte $\alpha 6$ -integrin expression has not been addressed previously. We have now shown that, the combined effects of the down-regulation of PDGFR β and the changes in pericyte adhesion, upon deletion of $\alpha 6\beta 1$ -integrin, induces destabilisation of tumour blood vessels. Genetic ablation of pericyte $\alpha 6\beta 1$ -integrin correlates with reduced pericyte investment to tumour blood vessels, changes in BM architecture and reduced PDGFR β expression levels and PDGF-BB-mediated downstream signalling. These correspond with increased blood vessel leakage without affecting tumour growth or metastasis. Together, our results suggest a dual function of $\alpha 6$ -integrin on pericytes and here we will discuss both the effect of reduced PDGFR β levels and decreased pericyte adhesion in turn.

Very few studies have linked pericyte integrins with growth factor receptor regulation. Currently, $\alpha 5\beta 1$ integrin has been shown to regulate signalling through PDGFR β , in vascular smooth muscle cells (Veevers-Lowe et al., 2011), and inactivation of PDGF-BB signalling can decrease $\alpha 1\beta 1$ integrin levels (Hosaka et al., 2013). In another study, NG2 depletion in pericytes was shown to reduce $\beta 1$ -integrin-mediated signalling (You et al., 2014). Although limited, these studies suggest possible cross-talk between pericyte integrins and growth factor receptors; a mechanism that has been shown previously between endothelial cell integrins and growth factor receptors (da Silva et al., 2010, Germain et al., 2010, Reynolds et al., 2002). In parallel, *in vitro* studies using fibroblasts have highlighted the ability of integrins to enhance PDGF-dependent responses (DeMali et al., 1999, Sundberg and Rubin, 1996). Here we show for the first time that $\alpha 6\beta 1$ -integrin acts as a regulator of PDGFR β – controlling its expression and signalling upon stimulation with PDGF-BB, in pericytes. Our data indicate that depletion of $\alpha 6$ -integrin on pericytes leads to a significant reduction in the levels of PDGFR β . In turn, this leads to a downregulation in the activation of the MAPKinase and AKT signalling pathways, which are both known to be critical for cell migration and proliferation (Lemmon and Schlessinger, 2010). Our observation of reduced pericyte

PDGFR β levels, signalling and resulting inhibited responses to PDGF-BB, in $\alpha 6$ -integrin deficient pericytes, may explain the tumour blood vessel phenotypes we observe in the *pdgfr β cre+; $\alpha 6$ fl/fl* mice; including reduced pericyte blood vessel investment and increased detachment of pericytes to endothelial cells, since these functions have been reported to be mediated by PDGF-BB (Abramsson et al., 2003, Hellberg et al., 2010). It has been well documented that tumours transplanted into PDGF-B retention motif-deficient (*pdgf-b^{ret/ret}*) mice have an approximately 50% reduction in numbers of pericytes that poorly associate with the blood vessel wall and result in leaky vessels (Abramsson et al., 2003). It is noteworthy that although we observe a similar leaky blood vessel phenotype to that reported in tumour growth in *pdgf-b^{ret/ret}* mice, our results indicate that $\alpha 6\beta 1$ integrin is a regulator of pericyte function rather than numbers, as seen in the *pdgf-b^{ret/ret}* mice (Lindblom et al., 2003).

One surprising observation was that despite such striking blood vessel defects in the *pdgfr β cre+; $\alpha 6$ fl/fl* mouse tumours, including increased vessel leakage, we did not observe any changes in tumour growth, angiogenesis or lung metastasis (Cooke et al., 2012, Zang et al., 2015). Our work is in line with previous studies showing that early ablation of NG2+ cells or PDGFR β R+ pericyte depletion does not necessarily affect tumour growth and metastasis (Keskin et al., 2015) suggesting that increased leakage alone is not sufficient to enhance metastasis. Indeed, increased vascular leakage has been shown to be insufficient for metastasis *per se* (Thurston et al., 1999). We hypothesise that despite the observed decrease in blood vessel pericyte coverage in *pdgfr β cre+; $\alpha 6$ fl/fl* mice, the remaining pericytes attached to the endothelial cells provide enough survival factors, for example VEGF and Ang-1, to allow ECs to survive, allowing for normal tumour angiogenesis and tumour growth. Studies have shown that decreased PC coverage can lead to regression of blood vessels but the magnitude is tumour specific and does not necessarily retard tumour growth (Sennino et al., 2007). Indeed, treatment of RipTag2 tumours with anti-PDGFR β antibody reduces pericyte numbers and enlarges blood vessels but does not reduce tumour vascular density

(Song et al., 2005). Although not within the scope of this study, we believe that the phenotype observed in our *pdgfr β cre⁺; α 6fl/fl* mice may help to improve chemotherapy efficacy to primary tumours, due to the leaky vessel defect.

As well as pericyte α 6-integrin deficiency affecting PDGFR β levels and upstream signalling, we also show that deletion of α 6-integrin affects the ECM adhesion properties of pericytes *in vitro* and *in vivo*. The BM that surrounds blood vessels is necessary for vessel integrity, stability and maturation. Recent studies have highlighted the importance of normal endothelial cell-pericyte interactions for proper BM organisation (Davis et al., 2013, Stratman et al., 2009, Baluk et al., 2003). When this interaction is de-stabilised, BM organisation is affected, resulting in decreased vessel integrity (Stratman et al., 2009, Davis et al., 2013). Therefore, it is possible that the phenotype we observe in the microvessel BM of *pdgfr β cre⁺; α 6fl/fl* mice may be due, at least in part, to a loss of pericyte adhesion to endothelial cell basement membrane. Similar phenotypes have been shown in other studies, for example: inactivation of the β 1-integrin subunit in mural cells leads to failure of these cells to associate with the subendothelial BM (Abraham et al., 2008); genetic ablation of a related laminin receptor, α 3-integrin results in an epidermal BM defect, in which components of the BM show a disorganised expression pattern (DiPersio et al., 1997, Georges-Labouesse et al., 1996, Has et al., 2012) very similar to that observed in tumour blood vessels of α 6-integrin pericyte deficient mice. Foxf2 (forkhead transcription factor, specifically expressed by pericytes) deficiency in brain pericytes leads to significantly reduced PDGFR β and α v β 8 integrin levels with thinning of the vascular basal lamina, resulting in a leaky blood brain barrier (Reyahi et al., 2015); inactivation of PDGF-BB signalling decreases α 1 β 1 integrin levels and impairs pericyte adhesion to extracellular matrix components of blood vessels (Hosaka et al., 2013).

Together these studies all support a common notion that crosstalk between pericyte integrins with PDGFR β signalling can affect vascular BM organisation and vessel function. It is also

conceivable that microvessel BM disorganisation may be a contributing cause of decreased supporting cell coverage in the tumour blood vessels in *pdgfr β cre⁺; α 6fl/fl* mice. For example, it has been shown that deletion of laminin- α 4 chain in mice causes impaired vessel growth due to reduced pericyte recruitment to blood vessels (Abrass et al., 2010). *In vitro*, pericyte recruitment during tube formation is necessary to stimulate endothelial BM formation (Stratman et al., 2009). Overall, our data suggest that the absence of pericyte α 6-integrin leads to i) the reduced investment of pericytes to tumour microvessels possibly due to reduced PDGFR β levels, and ii) this is associated with poor vessel BM architecture leading to vascular leakage.

Our study provides new insights into the regulation of tumour blood vessels by pericyte α 6-integrin which points towards an important role in the regulation of tumour vessel leakage.

Acknowledgments

We thank Julie Holdsworth (Bart Cancer Institute, QMUL, UK) and Bruce Williams (Cancer Research UK), for their technical help with animal experiments. Dr. Ralf Adams (Max Planck Institute for Molecular Biomedicine, Münster, Germany) generously provided the *pdgfr β cre* mice. Dr. Elisabeth Georges-Labouesse generously provided the *$\alpha 6$ floxed* mice. Rebecca Pike provided FACS technical support. This work was supported by a grant from Cancer Research UK (C8218/A18673)

Author contributions

L.E.R and K.M.H-D designed the experiments; L.E.R performed the experiments. T.L performed image analysis and mTmG studies. A.P. performed immune cell immunostaining and quantification. G. D performed confocal microscopy and retinal angiogenesis studies. J.M.M-F and L.E.R performed the FACS analysis. A.DA provided the $\alpha 6$ -integrin floxed mice. M.B undertook the initial tumour experiments. B.S performed the RPPA analysis. L.E.R and K.M.H.-D wrote the paper.

Conflict of interest

The authors declare no conflict of interest.

Abbreviations

BM, basement membrane; ECM, extracellular matrix; LLC, Lewis Lung Carcinoma

References

- ABRAHAM, S., KOGATA, N., FASSLER, R. & ADAMS, R. H. 2008. Integrin beta1 subunit controls mural cell adhesion, spreading, and blood vessel wall stability. *Circ Res*, 102, 562-70.
- ABRAMSSON, A., LINDBLOM, P. & BETSHOLTZ, C. 2003. Endothelial and nonendothelial sources of PDGF-B regulate pericyte recruitment and influence vascular pattern formation in tumors. *J Clin Invest*, 112, 1142-51.
- ABRASS, C. K., HANSEN, K. M. & PATTON, B. L. 2010. Laminin alpha4-null mutant mice develop chronic kidney disease with persistent overexpression of platelet-derived growth factor. *Am J Pathol*, 176, 839-49.
- ARMULIK, A., ABRAMSSON, A. & BETSHOLTZ, C. 2005. Endothelial/pericyte interactions. *Circ Res*, 97, 512-23.
- AVRAAMIDES, C. J., GARMY-SUSINI, B. & VARNER, J. A. 2008. Integrins in angiogenesis and lymphangiogenesis. *Nat Rev Cancer*, 8, 604-17.
- BAKER, M., ROBINSON, S. D., LECHERTIER, T., BARBER, P. R., TAVORA, B., D'AMICO, G., JONES, D. T., VOJNOVIC, B. & HODIVALA-DILKE, K. 2012. Use of the mouse aortic ring assay to study angiogenesis. *Nat Protoc*, 7, 89-104.
- BALUK, P., MORIKAWA, S., HASKELL, A., MANCUSO, M. & MCDONALD, D. M. 2003. Abnormalities of basement membrane on blood vessels and endothelial sprouts in tumors. *Am J Pathol*, 163, 1801-15.
- BENJAMIN, L. E., HEMO, I. & KESHET, E. 1998. A plasticity window for blood vessel remodelling is defined by pericyte coverage of the preformed endothelial network and is regulated by PDGF-B and VEGF. *Development*, 125, 1591-8.
- BOUVARD, C., DE ARCANGELIS, A., DIZIER, B., GALY-FAUROUX, I., FISCHER, A. M., GEORGES-LABOUESSE, E. & HELLEY, D. 2012. Tie2-dependent knockout of alpha6 integrin subunit in mice reduces post-ischaemic angiogenesis. *Cardiovasc Res*, 95, 39-47.
- COOKE, V. G., LEBLEU, V. S., KESKIN, D., KHAN, Z., O'CONNELL, J. T., TENG, Y., DUNCAN, M. B., XIE, L., MAEDA, G., VONG, S., SUGIMOTO, H., ROCHA, R. M., DAMASCENA, A., BRENTANI, R. R. & KALLURI, R. 2012. Pericyte depletion results in hypoxia-associated epithelial-to-mesenchymal transition and metastasis mediated by met signaling pathway. *Cancer Cell*, 21, 66-81.
- DA SILVA, R. G., TAVORA, B., ROBINSON, S. D., REYNOLDS, L. E., SZEKERES, C., LAMAR, J., BATISTA, S., KOSTOUROU, V., GERMAIN, M. A., REYNOLDS, A. R., JONES, D. T., WATSON, A. R., JONES, J. L., HARRIS, A., HART, I. R., IRUELA-ARISPE, M. L., DIPERSIO, C. M., KREIDBERG, J. A. & HODIVALA-DILKE, K. M. 2010. Endothelial alpha3beta1-integrin represses pathological angiogenesis and sustains endothelial-VEGF. *Am J Pathol*, 177, 1534-48.
- DAVIS, G. E., KIM, D. J., MENG, C. X., NORDEN, P. R., SPEICHINGER, K. R., DAVIS, M. T., SMITH, A. O., BOWERS, S. L. & STRATMAN, A. N. 2013. Control of vascular tube morphogenesis and maturation in 3D extracellular matrices by endothelial cells and pericytes. *Methods Mol Biol*, 1066, 17-28.
- DEMALI, K. A., BALCIUNAITIS, E. & KAZLAUSKAS, A. 1999. Integrins enhance platelet-derived growth factor (PDGF)-dependent responses by altering the signal relay enzymes that are recruited to the PDGF beta receptor. *J Biol Chem*, 274, 19551-8.
- DIPERSIO, C. M., HODIVALA-DILKE, K. M., JAENISCH, R., KREIDBERG, J. A. & HYNES, R. O. 1997. alpha3beta1 Integrin is required for normal development of the epidermal basement membrane. *J Cell Biol*, 137, 729-42.
- DURBEEJ, M. 2010. Laminins. *Cell Tissue Res*, 339, 259-68.
- FOO, S. S., TURNER, C. J., ADAMS, S., COMPAGNI, A., AUBYN, D., KOGATA, N., LINDBLOM, P., SHANI, M., ZICHA, D. & ADAMS, R. H. 2006. Ephrin-B2 controls cell motility and adhesion during blood-vessel-wall assembly. *Cell*, 124, 161-73.

- FURUHASHI, M., SJOBLÖM, T., ABRAMSSON, A., ELLINGSEN, J., MICKE, P., LI, H., BERGSTEN-FOLESTAD, E., ERIKSSON, U., HEUCHEL, R., BETSHOLTZ, C., HELDIN, C. H. & OSTMAN, A. 2004. Platelet-derived growth factor production by B16 melanoma cells leads to increased pericyte abundance in tumors and an associated increase in tumor growth rate. *Cancer Res*, 64, 2725-33.
- GARMY-SUSINI, B., JIN, H., ZHU, Y., SUNG, R. J., HWANG, R. & VARNER, J. 2005. Integrin $\alpha 4\beta 1$ -VCAM-1-mediated adhesion between endothelial and mural cells is required for blood vessel maturation. *J Clin Invest*, 115, 1542-51.
- GEORGES-LABOUESSE, E., MESSADDEQ, N., YEHIA, G., CADALBERT, L., DIERICH, A. & LE MEUR, M. 1996. Absence of integrin $\alpha 6$ leads to epidermolysis bullosa and neonatal death in mice. *Nat Genet*, 13, 370-3.
- GERMAIN, M., DE ARCANGELIS, A., ROBINSON, S. D., BAKER, M., TAVORA, B., D'AMICO, G., SILVA, R., KOSTOUROU, V., REYNOLDS, L. E., WATSON, A., JONES, J. L., GEORGES-LABOUESSE, E. & HODIVALA-DILKE, K. 2010. Genetic ablation of the $\alpha 6$ -integrin subunit in TIE1Cre mice enhances tumour angiogenesis. *J Pathol*, 220, 370-81.
- HAS, C., SPARTA, G., KIRITSIS, D., WEIBEL, L., MOELLER, A., VEGA-WARNER, V., WATERS, A., HE, Y., ANIKSTER, Y., ESSER, P., STRAUB, B. K., HAUSSER, I., BOCKENHAUER, D., DEKEL, B., HILDEBRANDT, F., BRUCKNER-TUDERMAN, L. & LAUBE, G. F. 2012. Integrin $\alpha 3$ mutations with kidney, lung, and skin disease. *N Engl J Med*, 366, 1508-14.
- HELLBERG, C., OSTMAN, A. & HELDIN, C. H. 2010. PDGF and vessel maturation. *Recent Results Cancer Res*, 180, 103-14.
- HOSAKA, K., YANG, Y., SEKI, T., NAKAMURA, M., ANDERSSON, P., ROUHI, P., YANG, X., JENSEN, L., LIM, S., FENG, N., XUE, Y., LI, X., LARSSON, O., OHHASHI, T. & CAO, Y. 2013. Tumour PDGF-BB expression levels determine dual effects of anti-PDGF drugs on vascular remodelling and metastasis. *Nat Commun*, 4, 2129.
- HUANG, F. J., YOU, W. K., BONALDO, P., SEYFRIED, T. N., PASQUALE, E. B. & STALLCUP, W. B. 2010. Pericyte deficiencies lead to aberrant tumor vascularization in the brain of the NG2 null mouse. *Dev Biol*, 344, 1035-46.
- JANSSEN, H. L., LJUNGKVIST, A. S., RIJKEN, P. F., SPRONG, D., BUSSINK, J., VAN DER KOGEL, A. J., HAUSERMANS, K. M. & BEGG, A. C. 2005. Thymidine analogues to assess microperfusion in human tumors. *International Journal of Radiation Oncology Biology Physics*, 62, 1169-1175.
- KESKIN, D., KIM, J., COOKE, V. G., WU, C. C., SUGIMOTO, H., GU, C., DE PALMA, M., KALLURI, R. & LEBLEU, V. S. 2015. Targeting vascular pericytes in hypoxic tumors increases lung metastasis via angiopoietin-2. *Cell Rep*, 10, 1066-81.
- LEMMON, M. A. & SCHLESSINGER, J. 2010. Cell signaling by receptor tyrosine kinases. *Cell*, 141, 1117-34.
- LINDBLÖM, P., GERHARDT, H., LIEBNER, S., ABRAMSSON, A., ENGE, M., HELLSTROM, M., BACKSTROM, G., FREDRIKSSON, S., LANDEGREN, U., NYSTROM, H. C., BERGSTROM, G., DEJANA, E., OSTMAN, A., LINDAHL, P. & BETSHOLTZ, C. 2003. Endothelial PDGF-B retention is required for proper investment of pericytes in the microvessel wall. *Genes Dev*, 17, 1835-40.
- LIU, S. & LEASK, A. 2012. Integrin $\beta 1$ is required for maintenance of vascular tone in postnatal mice. *J Cell Commun Signal*, 6, 175-80.
- MUZUMDAR, M. D., TASIC, B., MIYAMICHI, K., LI, L. & LUO, L. 2007. A global double-fluorescent Cre reporter mouse. *Genesis*, 45, 593-605.
- NICOSIA, R. F. 2009. The aortic ring model of angiogenesis: a quarter century of search and discovery. *J Cell Mol Med*, 13, 4113-36.
- PATEL, S. R., JENKINS, J., PAPADOPOULOS, N., BURGESS, M. A., PLAGER, C., GUTTERMAN, J. & BENJAMIN, R. S. 2001. Pilot study of Vitaxin - An angiogenesis inhibitor - In patients with advanced leiomyosarcomas. *Cancer*, 92, 1347-1348.

- PIERCE, R. A., GRIFFIN, G. L., MINER, J. H. & SENIOR, R. M. 2000. Expression patterns of laminin alpha1 and alpha5 in human lung during development. *Am J Respir Cell Mol Biol*, 23, 742-7.
- PLATTA, H. W. & STENMARK, H. 2011. Endocytosis and signaling. *Curr Opin Cell Biol*, 23, 393-403.
- REYAH, A., NIK, A. M., GHAMI, M., GRITLI-LINDE, A., PONTEN, F., JOHANSSON, B. R. & CARLSSON, P. 2015. Foxf2 Is Required for Brain Pericyte Differentiation and Development and Maintenance of the Blood-Brain Barrier. *Dev Cell*, 34, 19-32.
- REYNOLDS, L. E. & HODIVALA-DILKE, K. M. 2006. Primary mouse endothelial cell culture for assays of angiogenesis. *Methods Mol Med*, 120, 503-9.
- REYNOLDS, L. E., WATSON, A. R., BAKER, M., JONES, T. A., D'AMICO, G., ROBINSON, S. D., JOFFRE, C., GARRIDO-URBANI, S., RODRIGUEZ-MANZANEQUE, J. C., MARTINO-ECHARRI, E., AURRAND-LIONS, M., SHEER, D., DAGNA-BRICARELLI, F., NIZETIC, D., MCCABE, C. J., TURNELL, A. S., KERMORGANT, S., IMHOF, B. A., ADAMS, R., FISHER, E. M., TYBULEWICZ, V. L., HART, I. R. & HODIVALA-DILKE, K. M. 2010. Tumour angiogenesis is reduced in the Tc1 mouse model of Down's syndrome. *Nature*, 465, 813-7.
- REYNOLDS, L. E., WYDER, L., LIVELY, J. C., TAVERNA, D., ROBINSON, S. D., HUANG, X., SHEPPARD, D., HYNES, R. O. & HODIVALA-DILKE, K. M. 2002. Enhanced pathological angiogenesis in mice lacking beta3 integrin or beta3 and beta5 integrins. *Nat Med*, 8, 27-34.
- SASAKI, T., MANN, K. & TIMPL, R. 2001. Modification of the laminin alpha 4 chain by chondroitin sulfate attachment to its N-terminal domain. *FEBS Lett*, 505, 173-8.
- SENNINO, B., FALCON, B. L., MCCAULEY, D., LE, T., MCCAULEY, T., KURZ, J. C., HASKELL, A., EPSTEIN, D. M. & MCDONALD, D. M. 2007. Sequential loss of tumor vessel pericytes and endothelial cells after inhibition of platelet-derived growth factor B by selective aptamer AX102. *Cancer Res*, 67, 7358-67.
- SONG, S., EWALD, A. J., STALLCUP, W., WERB, Z. & BERGERS, G. 2005. PDGFRbeta+ perivascular progenitor cells in tumours regulate pericyte differentiation and vascular survival. *Nat Cell Biol*, 7, 870-9.
- STRATMAN, A. N., MALOTTE, K. M., MAHAN, R. D., DAVIS, M. J. & DAVIS, G. E. 2009. Pericyte recruitment during vasculogenic tube assembly stimulates endothelial basement membrane matrix formation. *Blood*, 114, 5091-101.
- STRATMAN, A. N., SCHWINDT, A. E., MALOTTE, K. M. & DAVIS, G. E. 2010. Endothelial-derived PDGF-BB and HB-EGF coordinately regulate pericyte recruitment during vasculogenic tube assembly and stabilization. *Blood*, 116, 4720-30.
- SUNDBERG, C. & RUBIN, K. 1996. Stimulation of beta1 integrins on fibroblasts induces PDGF independent tyrosine phosphorylation of PDGF beta-receptors. *J Cell Biol*, 132, 741-52.
- TABATABAI, G., WELLER, M., NABORS, B., PICARD, M., REARDON, D., MIKKELSEN, T., RUEGG, C. & STUPP, R. 2010. Targeting integrins in malignant glioma. *Targeted Oncology*, 5, 175-181.
- THURSTON, G., SUR, C., SMITH, K., MCCLAIN, J., SATO, T. N., YANCOPOULOS, G. D. & MCDONALD, D. M. 1999. Leakage-resistant blood vessels in mice transgenically overexpressing angiopoietin-1. *Science*, 286, 2511-4.
- TIGGES, U., WELSER-ALVES, J. V., BOROUJERDI, A. & MILNER, R. 2012. A novel and simple method for culturing pericytes from mouse brain. *Microvasc Res*, 84, 74-80.
- TURNER, C. J., BADU-NKANSAH, K., CROWLEY, D., VAN DER FLIER, A. & HYNES, R. O. 2014. Integrin-alpha5beta1 is not required for mural cell functions during development of blood vessels but is required for lymphatic-blood vessel separation and lymphovenous valve formation. *Dev Biol*, 392, 381-92.
- VEEVERS-LOWE, J., BALL, S. G., SHUTTLEWORTH, A. & KIELTY, C. M. 2011. Mesenchymal stem cell migration is regulated by fibronectin through alpha5beta1-

- integrin-mediated activation of PDGFR-beta and potentiation of growth factor signals. *J Cell Sci*, 124, 1288-300.
- YAMADA, S., BU, X. Y., KHANKALDYAN, V., GONZALES-GOMEZ, I., MCCOMB, J. G. & LAUG, W. E. 2006. Effect of the angiogenesis inhibitor cilengitide (EMD 121974) on glioblastoma growth in nude mice. *Neurosurgery*, 59, 1304-1312.
- YOU, W. K., YOTSUMOTO, F., SAKIMURA, K., ADAMS, R. H. & STALLCUP, W. B. 2014. NG2 proteoglycan promotes tumor vascularization via integrin-dependent effects on pericyte function. *Angiogenesis*, 17, 61-76.
- ZANG, G., GUSTAFSSON, K., JAMALPOUR, M., HONG, J., GENOVE, G. & WELSH, M. 2015. Vascular dysfunction and increased metastasis of B16F10 melanomas in Shb deficient mice as compared with their wild type counterparts. *BMC Cancer*, 15, 234.
- ZHANG, H. B., BAJRASZEWSKI, N., WU, E. X., WANG, H. W., MOSEMAN, A. P., DABORA, S. L., GRIFFIN, J. D. & KWIATKOWSKI, D. J. 2007. PDGFRs are critical for PI3K/Akt activation and negatively regulated by mTOR. *Journal of Clinical Investigation*, 117, 730-738.

Figure Legends

Figure 1. Reduced pericyte investment and increased vessel leakage in *pdgfr β cre+; α 6fl/fl* mice.

(A) B16F0 tumour sections from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice were double-immunostained for NG2 (red) and α 6-integrin (green) expression to determine *in vivo* expression of α 6-integrin in pericytes. α 6-integrin was observed in NG2-positive pericytes in tumour blood vessels from *pdgfr β cre-; α 6fl/fl* mice. In contrast, α 6-integrin expression was significantly reduced in pericytes in tumour blood vessels from *pdgfr β cre+; α 6fl/fl* mice. Magnified regions show α 6-integrin positive pericytes (to give a yellow signal) on *pdgfr β cre-; α 6fl/fl* blood vessels but α 6-integrin negative pericytes on *pdgfr β cre+; α 6fl/fl* blood vessels. **Arrows**, α 6/NG2 co-expression; **arrowheads**, NG2 expression alone. (B) Quantitation of α 6-integrin expression in NG2-positive pericytes from tumour blood vessels in *pdgfr β cre-; α 6fl/fl* in *pdgfr β cre+; α 6fl/fl* mice. Bar chart represents mean pixel intensity of α 6-integrin expression in NG2-positive cells+SEM; n=9-10 tumours per genotype. (C) Pericyte association with blood vessels. The % of blood vessels with associated NG2-positive pericytes in B16F0 and LLC tumours grown in *pdgfr β cre+; α 6fl/fl* mice was reduced significantly compared with *pdgfr β cre-; α 6fl/fl* mice. Scatter graphs represent % blood vessels that are NG2-positive in B16F0 and LLC tumours+SEM; n= 4-6 mice/group. Representative images of tumour sections stained with the pericyte marker, NG2 (green) and endomucin (red). **Arrows**, endomucin positive staining; **arrowheads**, NG2 positive staining. (D) Blood vessel diameter. The frequency of vessels with a diameter ≥ 100 μ m was greater in both B16F0 and LLC tumours grown in *pdgfr β cre+; α 6fl/fl* mice when compared with *pdgfr β cre-; α 6fl/fl* mice. Bar charts represent the % of blood vessels ≥ 100 μ m diameter+SEM. (E) Blood vessel leakage. Mice were injected via the tail vein with Hoechst dye and tumour sections were analysed for blood vessel leakage by measuring the numbers of tumour cells that had taken up Hoechst. Blood vessels in the tumours grown in *pdgfr β cre+; α 6fl/fl* mice showed

significantly more leakage than blood vessels in tumours grown in *pdgfr β cre-; α 6fl/fl* mice. Bar chart shows relative Hoechst leakage+SEM; n= 6 tumours/genotype. **Dotted lines**, Hoechst leakage. **p* <0.05, ***p* <0.005, ****p* <0.0009. Scale bar in A= 50 μ m, C= 100 μ m and E= 200 μ m.

Figure 2. Tumours grown in *pdgfr β cre+; α 6fl/fl* mice have aberrant BM organisation around blood vessels.

LLC tumours were stained with antibodies to the extracellular matrix proteins (A) collagen IV, (B) fibronectin, (C) laminin α 5 and (D) laminin α 4 chains. For all matrices, disorganisation of basement membrane with a “shoreline” pattern was observed more frequently around blood vessels in tumours grown in *pdgfr β cre+; α 6fl/fl* mice when compared with *pdgfr β cre-; α 6fl/fl* mice. (E) The width of the BM surrounding blood vessels was analysed. Boxes show magnified regions of BM. **Brackets**, identify representative BM widths. n= 8-10 sections/genotype; ***p* <0.005. Scale bars = 50 μ m.

Figure 3. Tumour growth, angiogenesis and metastasis are not affected in *pdgfr β cre+; α 6fl/fl* mice.

(A) Subcutaneous B16F0 and LLC tumour growth was similar in both *pdgfr β cre+; α 6fl/fl* mice and *pdgfr β cre-; α 6fl/fl* mice. Bar charts represent mean tumour volumes \pm SEM; n=20-30 mice/genotype. (B) Endomucin staining of midline sections of age- and size-matched B16F0 and LLC tumours showed no significant differences in blood vessel density between *pdgfr β cre+; α 6fl/fl* mice and *pdgfr β cre-; α 6fl/fl* mice. Blood vessel density is given as the number of blood vessels/mm² of midline tumour section. Representative images of endomucin stained tumour blood vessels are shown. Bar chart represents mean tumour blood vessel density of size-matched tumours+SEM; n= 6 tumour sections/genotype, ns=no significant difference. (C) The number of perfused tumour blood vessels was assessed by tail vein injection of PE-CD31 antibody before tumour excision in *pdgfr β cre+; α 6fl/fl* mice and

pdgfr β cre-; α 6fl/fl control mice and comparing the numbers of CD31-positive vessels with numbers of endomucin stained vessels. B16F0 and LLC tumours grown in *pdgfr β cre+; α 6fl/fl* mice had a similar number of functional PE-CD31 endomucin expressing tumour blood vessels compared to *pdgfr β cre-; α 6fl/fl* littermate control mice. Bar charts represent the percentage of PE-CD31 perfused vessels over total number of endomucin positive blood vessels per midline tumour section from *pdgfr β cre+; α 6fl/fl* mice and *pdgfr β cre-; α 6fl/fl* mice + SEM; n=10 tumour sections per genotype, ns=no significant difference. Representative images of endomucin stained, PE-CD31 positive perfused blood vessels from B16F0 tumours are shown. **(D)** Metastasis is not affected in *pdgfr β cre+; α 6fl/fl* mice. Subcutaneous LLC tumours were resected when they reached approximately 100 mm³. At 3 weeks post-resection mice were culled and lungs removed to assess metastasis. Lungs were fixed and the number of surface metastases was counted. There were no significant differences in the total number of surface metastases between *pdgfr β cre+; α 6fl/fl* mice and *pdgfr β cre-; α 6fl/fl* mice (bar chart). Lungs were then sectioned and stained with H&E. Measurement of individual metastatic nodule areas showed no difference between genotypes (scatter graph). Representative high power images of H&E stained lung sections show areas of metastasis (dotted line) (upper images) as well as low power images of metastatic lung tissue (*arrows*) (lower images). Scale bar in B= 100 μ m, C= 50 μ m, D= 50 μ m (upper panel), 5000 μ m (lower panel).

Figure 4. Pericyte α 6-integrin regulates PDGFR β expression

(A) Pericytes were isolated from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice, and Western blot analysis performed to assess α 6-integrin deletion. α 6 deletion was only observed in pericytes from *pdgfr β cre+; α 6fl/fl* mice. FACS analysis also confirmed loss of α 6-integrin surface levels in pericytes isolated from *pdgfr β cre+; α 6fl/fl* mice compared with pericytes isolated from *pdgfr β cre-; α 6fl/fl* mice (line graph and equivalent data dot plot). Bar charts represent densitometric readings of Western blots, corrected for loading. N=3 separate

lysates/genotype. **(B)** Western blot analysis confirmed that WT and $\alpha 6$ -null pericytes have similar levels of $\alpha 3$ -integrin, a second laminin receptor, suggesting that there was no compensation of $\alpha 3$ -integrin in the absence of $\alpha 6$ -integrin. N=3 separate lysates/genotype. **(C)** Fibroblasts and endothelial cells were isolated from *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice and Western blot analysis performed to assess $\alpha 6$ -integrin levels. $\alpha 6$ -integrin levels were not affected in either cell type isolated from either *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice. **(D)** Western blot analysis revealed PDGFR β protein levels were significantly reduced in primary $\alpha 6$ -null pericytes. Bar chart shows densitometric values of PDGFR β levels, corrected for loading. HSC70 was used as a loading control; n=3 separate lysates/genotype; **p* <0.05; ns=no significant difference. **(E)** Immunostaining of PDGFR β in $\alpha 6$ -null pericytes in culture was significantly reduced compared with WT pericytes. Scale bar in E = 50 μ m.

Figure 5. Responses to PDGF-BB are reduced in $\alpha 6$ -null pericytes

(A) Aortic rings were isolated from *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice and treated with either PBS or PDGF-BB (30 ng/ml) for up to 10 days. PDGF-BB stimulation increased vessel sprouting in *pdgfr β cre-; $\alpha 6$ fl/fl* but not *pdgfr β cre+; $\alpha 6$ fl/fl* aortic rings. Bar charts show average number of aortic sprouts/genotype+SEM; n=40-50 rings/genotype in triplicate. **(B)** Confluent monolayers of primary WT and $\alpha 6$ -null pericytes were wounded manually, after 24 h serum starvation, then stimulated, or not, with PDGF-BB (30 ng/ml). Wound width was quantified up to 48 h. Wound closure was significantly reduced in $\alpha 6$ -null pericytes in response to PDGF-BB. Bar charts show wound width in the absence (left panel) or presence (right panel) of PDGF-BB, normalised to time 0; n=6/genotype/time point in triplicate. **(C)** Proliferation of primary WT and $\alpha 6$ -null pericytes in the presence of Optimem or PDGF-BB was measured. $\alpha 6$ -null pericytes proliferated significantly less in the presence of PDGF-BB compared with WT pericytes. Graphs represent relative proliferation; n=3

biological repeats. **(D)** Western blot analysis of phosphorylated-ERK1/2, total ERK1/2, phosphorylated-AKT and total AKT, from WT and $\alpha 6$ -null pericyte lysates after serum starvation and stimulation with PDGF-BB for 0, 30 s, 60 s, 5 min, 15 min, 30 min. Downstream signalling responses to PDGF-BB in $\alpha 6$ -null pericytes were reduced significantly. Individual cropped blots are representative of samples run on the same gel under identical experimental conditions. HSC70 acted as the loading control. **(E)** Graphs show densitometric readings of fold change of ratios p-AKT/totalAKT to time 0; fold change of ratios p-ERK1/2/totalERK1/2 to time 0 \pm s.e.m. N=3 independent experiments. * $p < 0.05$, ** $p < 0.005$.

SUPPLEMENTARY INFORMATION

Dual role of pericyte $\alpha 6 \beta 1$ -integrin in tumour blood vessels

Louise E. Reynolds¹*, Gabriela D'Amico-Lago^{1*}, Tanguy Lechertier^{1*}, Alexandros Papachristodoulou^{2*}, José M. Muñoz-Félix¹, Adèle De Arcangelis³, Marianne Baker¹,
Bryan Serrels⁴ and Kairbaan M. Hodivala-Dilke¹

¹Adhesion and Angiogenesis Laboratory, Centre for Tumour Biology,
Barts Cancer Institute- A CRUK Centre of Excellence,
Queen Mary University of London,
Charterhouse Square,
London, UK.
EC1M 6BQ.

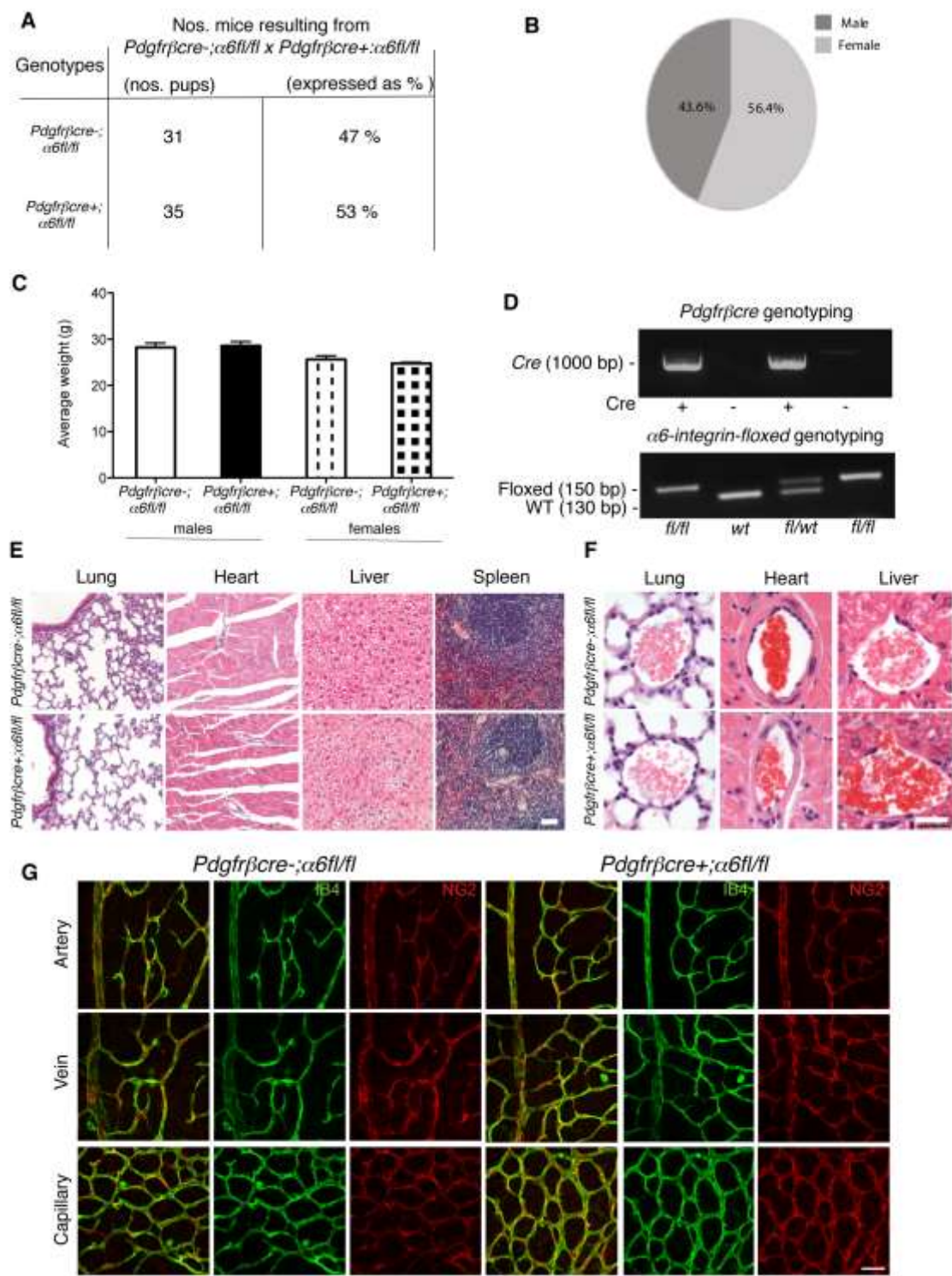
²Laboratory for Molecular Neuro-Oncology,
Dept. of Neurology,
University Hospital Zurich,
Frauenklinikstrasse 26,
CH-8091 Zurich,
Switzerland.

³IGBMC,
UMR 7104, INSERM U964, Université de Strasbourg,
BP. 10142,
1, Rue Laurent Fries,
67404 Illkirch Cedex,
France.

⁴Cancer Research UK Edinburgh Centre,
University of Edinburgh,
Crewe Road South,
Edinburgh, UK.
EH4 2XR.

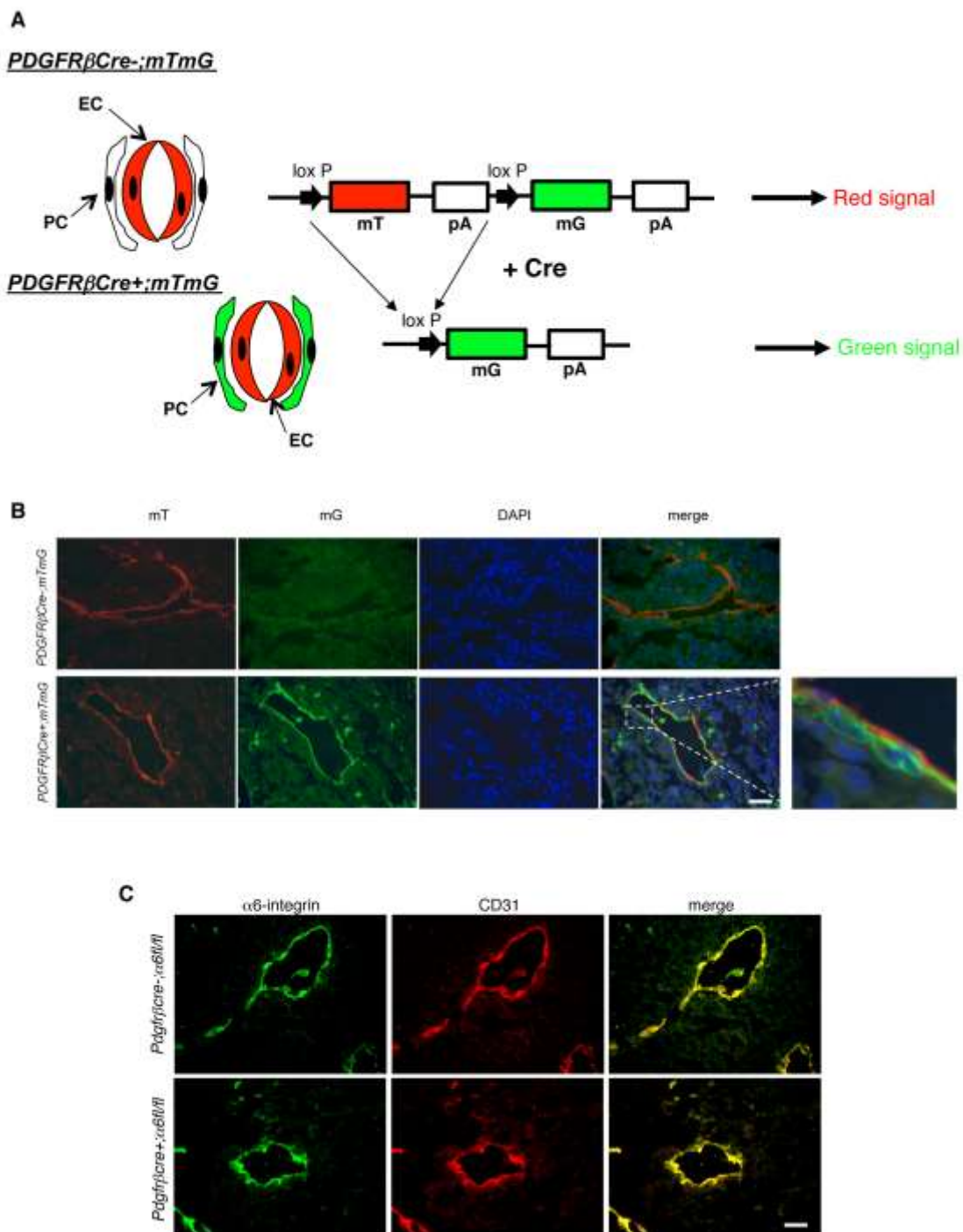
*These authors contributed equally

✉Corresponding author: l.reynolds@qmul.ac.uk



Supplementary Figure 1. Characterisation of *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice and morphological analysis of tissue and postnatal retinal angiogenesis. (A) *Pdgfr β cre-; α 6fl/fl* mice crossed to *pdgfr β cre+; α 6fl/fl* mice produce: litters that had a similar

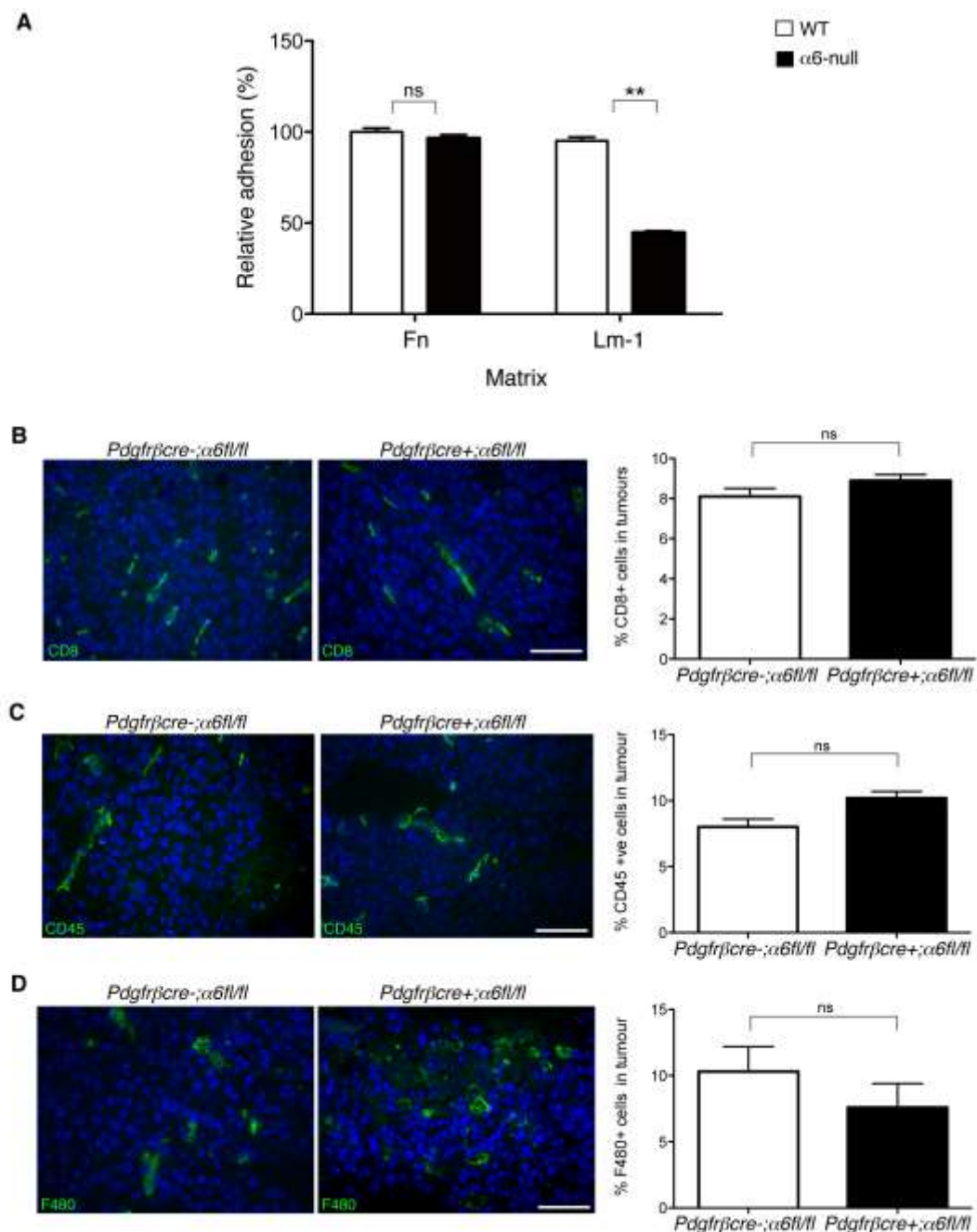
number of *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice in predicted Mendelian ratios, **(B)** and similar ratios of *pdgfr β cre+; α 6fl/fl* males and females, identified at weaning. **(C)** Mice were weighed at 3 months old. No differences were observed in the weights of sex-matched mice between the two genotypes. **(D)** All mice were analysed by PCR genotyping and shows a product identifying *pdgfr β cre+* PCR at approx. 1000 bp. α 6-integrin-floxed PCR shows products identifying homozygous α 6-integrin floxed (α 6fl/fl) (154 bp), WT non-floxed (α 6-integrin wt) (120 bp), and heterozygous (α 6-integrin fl/wt) mice (154 bp and 120 bp). **(E)** Representative H&E stained sections of lung, heart, liver and spleen from 12 week old *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice. No gross morphological defects were observed. **(F)** Representative high power images of blood vessels in lung, heart and liver from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice showed no obvious morphological blood vascular defects between the genotypes. **(G)** Confocal microscopy images show 3D Z-stack reconstructions of flat whole-mount immunofluorescent stained retinas from *pdgfr β cre-; α 6fl/fl* and *pdgfr β cre+; α 6fl/fl* mice at postnatal day (P) 9. Arterial, vein and capillary vessels in the superficial retinal plexus are visualised with Isolectin B4 (IB4, green). Pericytes are identified with NG2 (red); n=4 retinas/genotype. Scale bar in **E**=20 μ m; **F**=100 μ m; **G**=50 μ m.



Supplementary Figure 2. mTmG reporter activity in pericytes after PDGFR β Cre excision. *mTmG* mice are used as a reporter of Cre activity in Cre⁺ mice. We generated *pdgfr β cre⁻;mTmG* and *pdgfr β cre⁺;mTmG* mice. (A) Schematic representation of the mTmG reporter effect in *pdgfr β cre⁺* mice. In non-Cre expressing cells mT (red) signal is observed in endothelial cells (EC). In Cre expressing cells the mT transgene is excised and the mG

(green) signal is observed in pericytes (PC). **(B)** B16F0 tumour cells were injected subcutaneously into *pdgfr β cre⁻;mTmG* and *pdgfr β cre⁺;mTmG* mice and tumours excised 12 days post inoculation. Tumour blood vessels were examined for expression of both membrane-targeted tandem dimer Tomato (mT) (red), seen in all host tissue and membrane-targeted green fluorescent protein (GFP) (mG) (green). GFP expression was observed only in *pdgfr β cre⁺;mTmG* mice, as expected and almost exclusively in PCs surrounding blood vessels (*white box*, magnified region). **(C)** Tumour blood vessels immunostained with antibodies to α 6-integrin and CD31 revealed co-expression of the 2 markers, showing that α 6-integrin expression is not affected on endothelial cells *in vivo*. Scale bars in **B**, **C** =50 μ m.

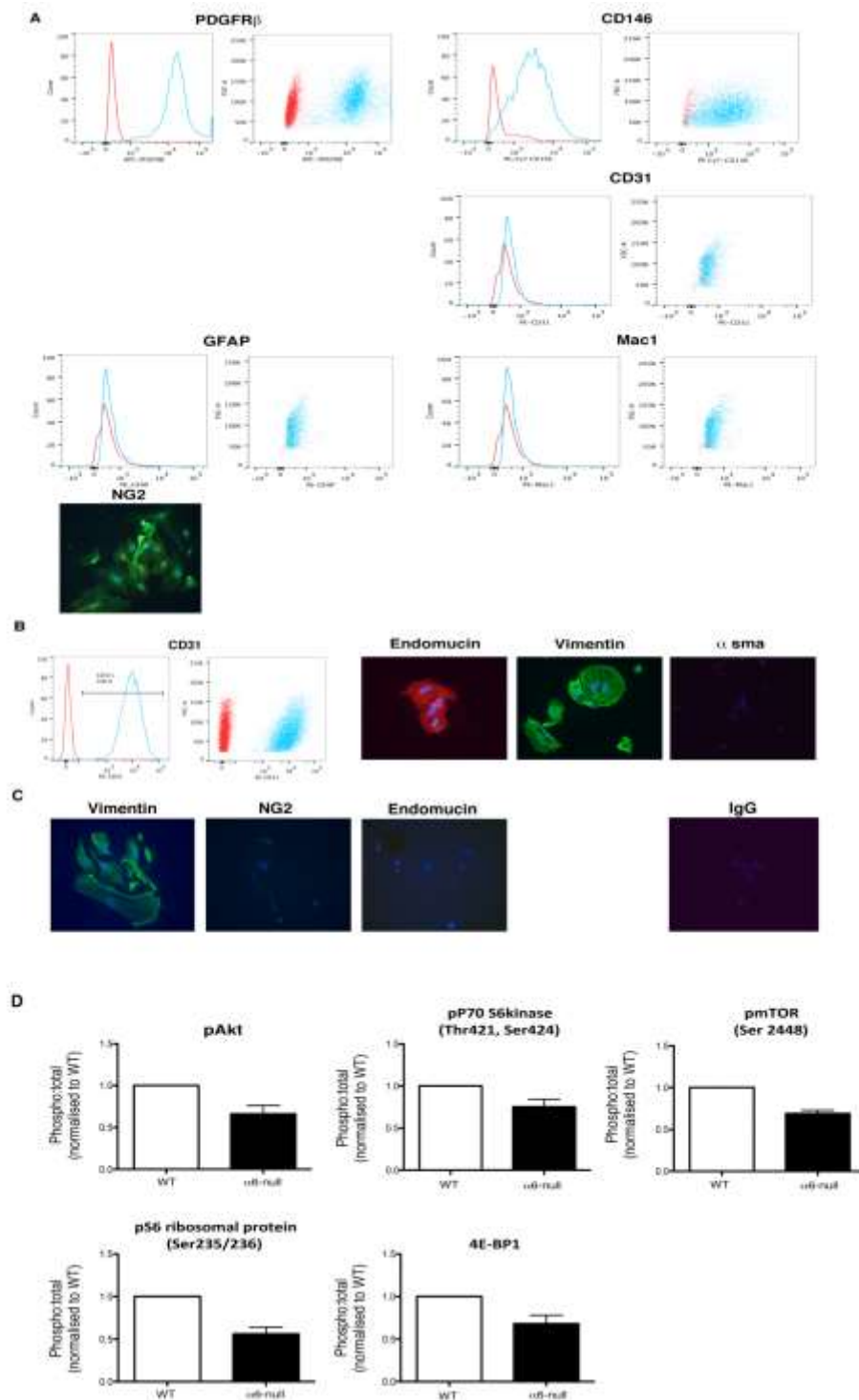
Supplementary Figure 3 Reynolds *et al*



Supplementary Figure 3. Adhesion of wild-type and α6-null pericytes to Laminin-1 and immune cell infiltration in tumours.

(A) 5×10^4 wild-type (WT) and α6-null mouse brain pericytes were allowed to adhere to Laminin-1 (Lm-1; 10μg/ml) and Fibronectin (Fn; 10μg/ml) coated 96-well plates for 1 h at 37°C. α6-null pericytes do not bind effectively to the Lm-1 matrix compared with WT

pericytes. No difference in Fn adhesion was observed between WT and $\alpha 6$ -null pericytes. Bar chart represents % adhesion of pericytes to Lm-1 relative to adhesion to Fn for the same genotype. n=3 biological repeats; **p<0.01. Sections from tumours grown in *pdgfr β cre-; $\alpha 6$ fl/fl* and *pdgfr β cre+; $\alpha 6$ fl/fl* mice were stained with antibodies to inflammatory cell markers **(B)** CD8 (T cells), **(C)** CD45 cells and **(D)** F480 (macrophages). No difference in inflammatory cell infiltration was observed between tumours from either genotype. Bar charts represent % immune cell infiltration; n=6 tumours/genotype; ns= not significantly different. Scale bar =100 μ m.



Supplementary Figure 4. Characterisation of primary mouse brain pericytes, primary mouse lung endothelial cells and fibroblasts and Reverse Phase Protein Array (RPPA) analysis reveals the mTOR signalling pathway is attenuated in α 6-null mouse brain pericytes. (A) Primary mouse brain pericytes were characterised using the following markers, by FACS: PDGFR β , CD146, CD31 (endothelial marker), glial fibrillary acidic protein

Figure 1 Reynolds *et al*

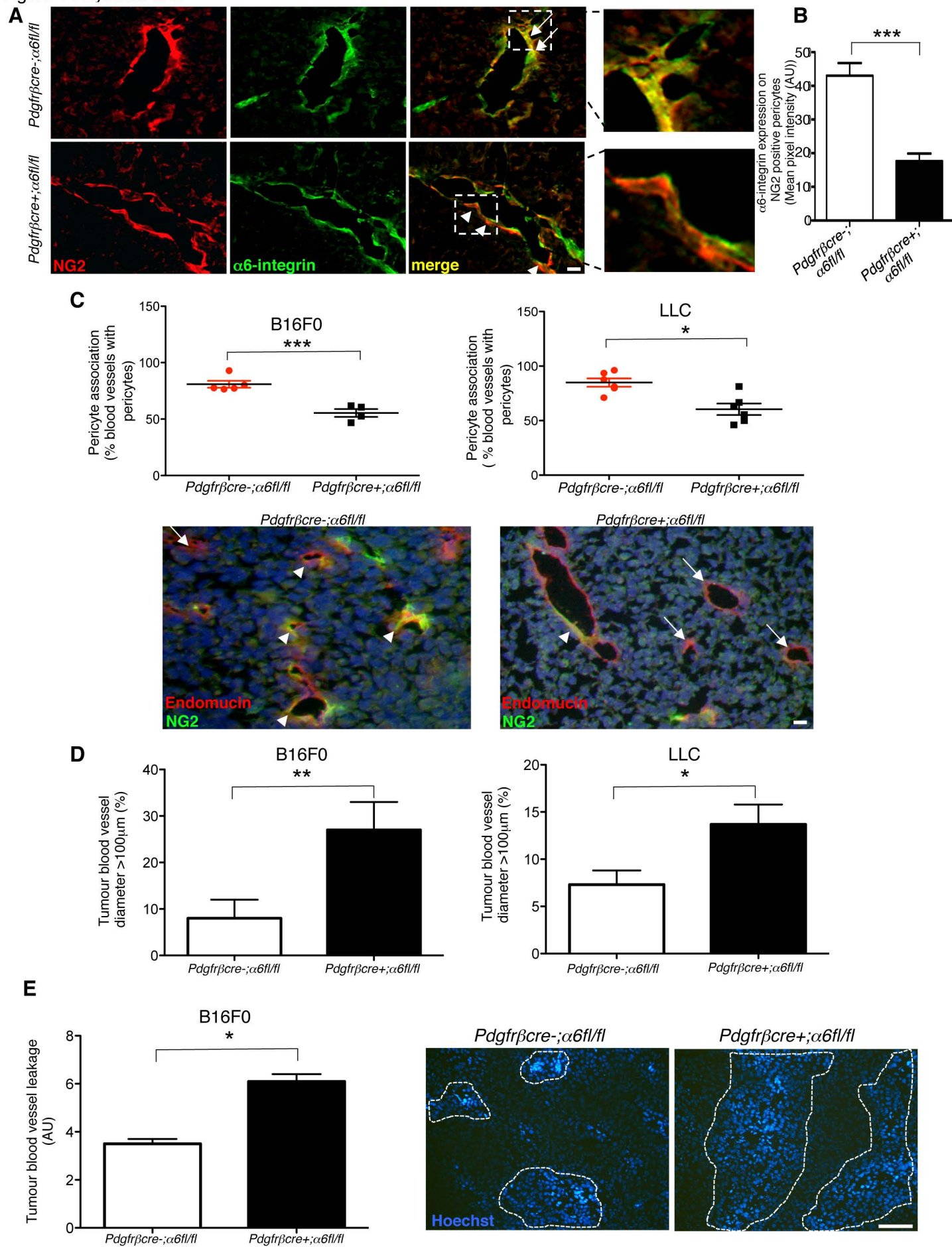


Figure 2 Reynolds *et al*

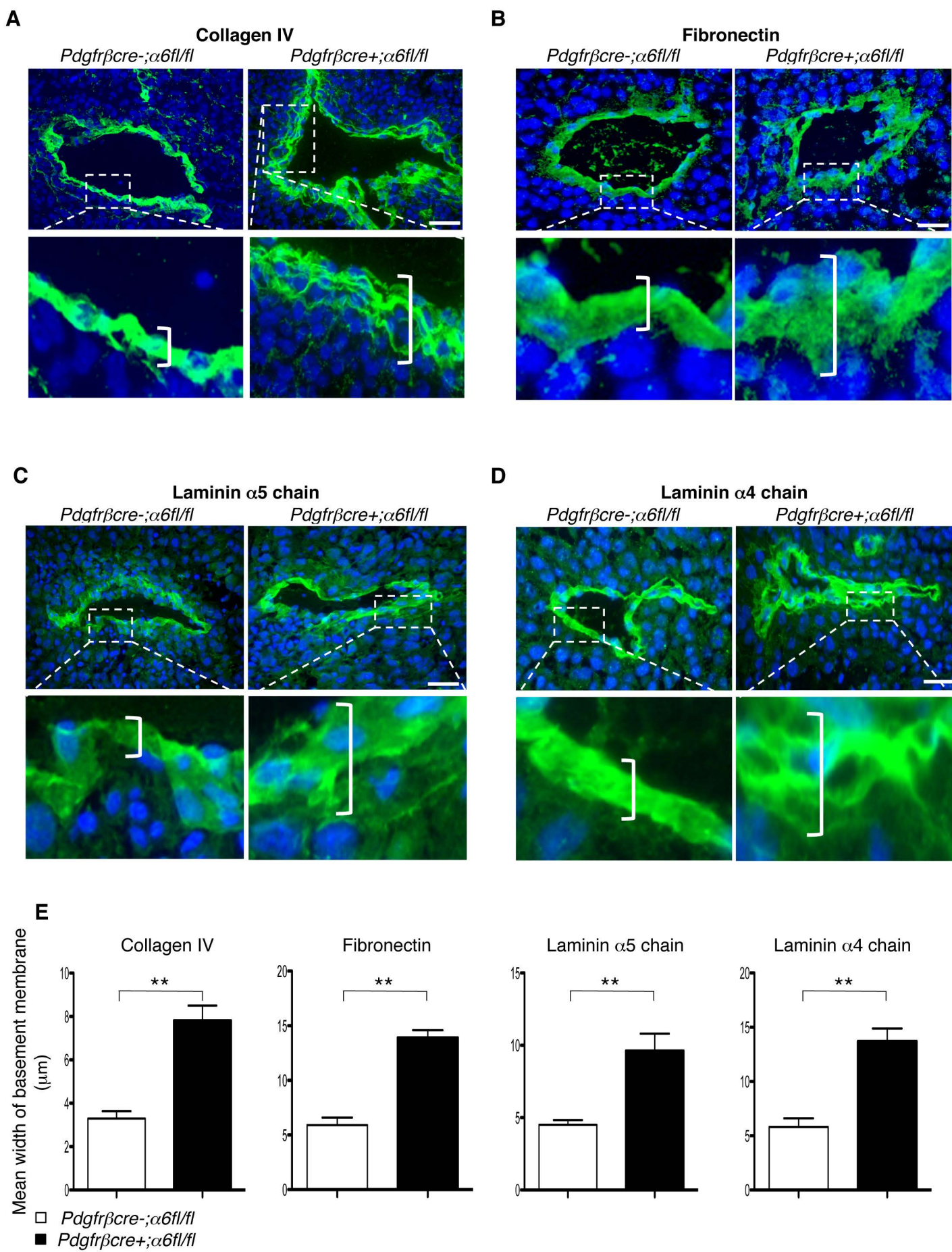


Figure 3 Reynolds *et al*

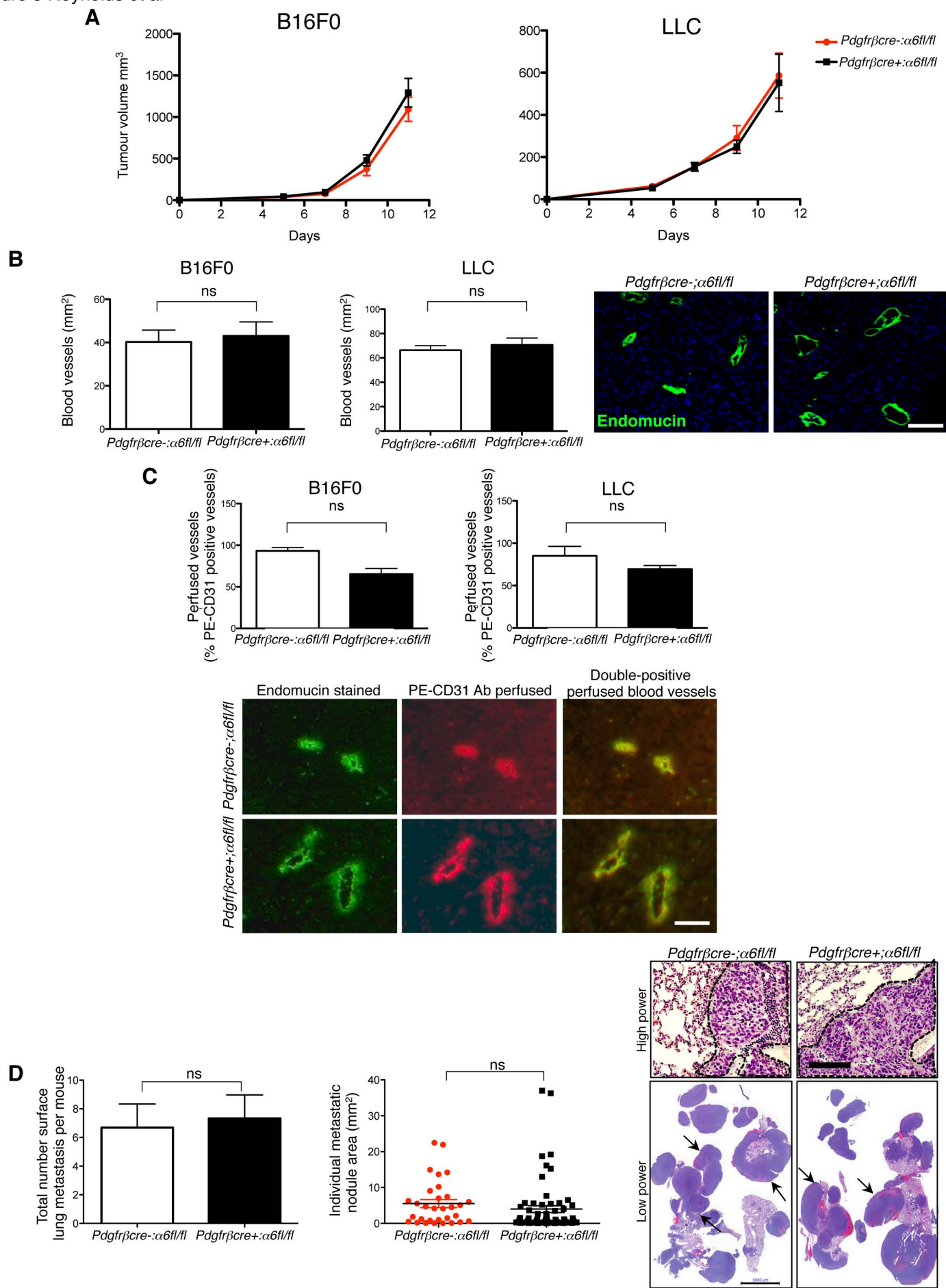


Figure 4. Reynolds *et al*

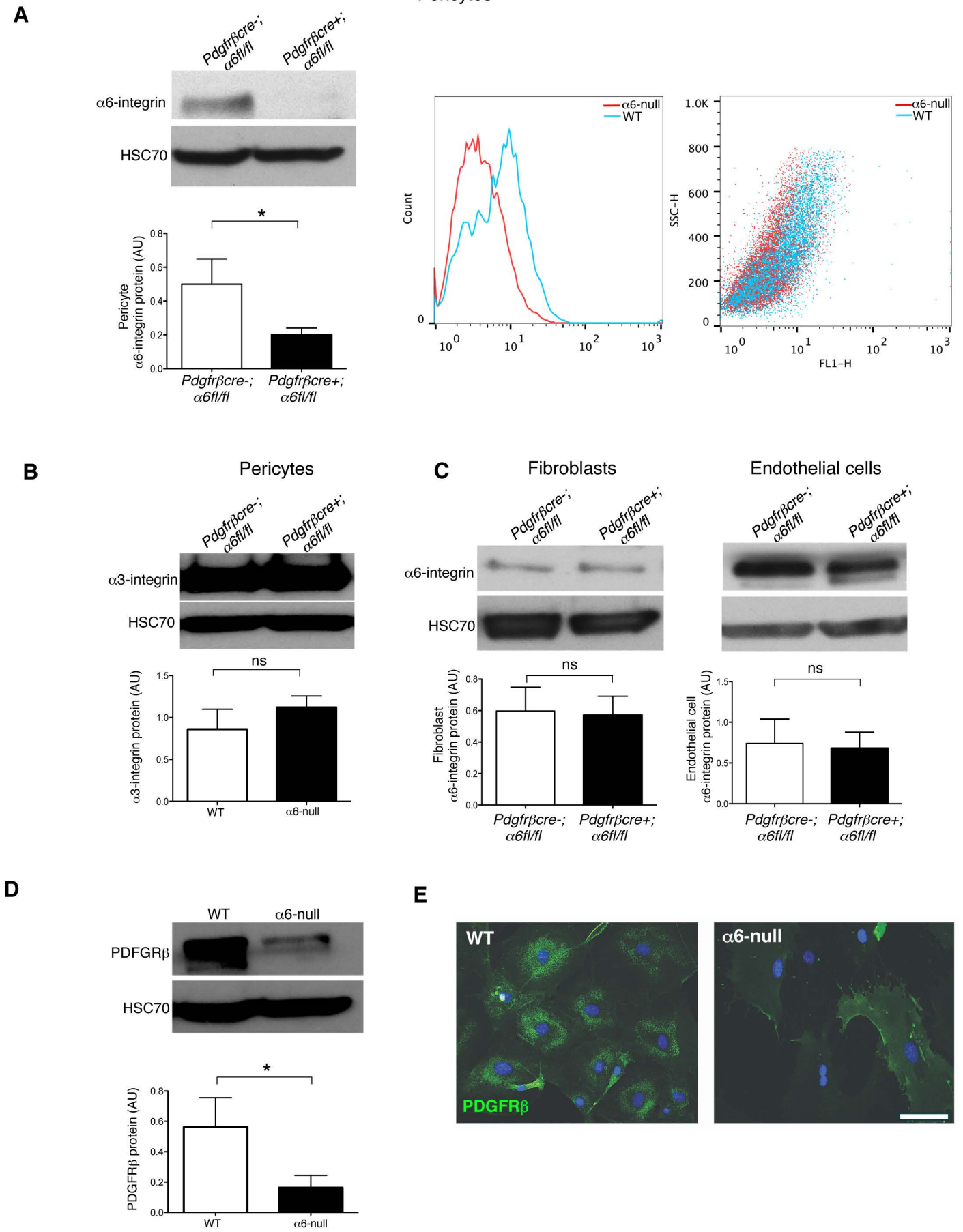
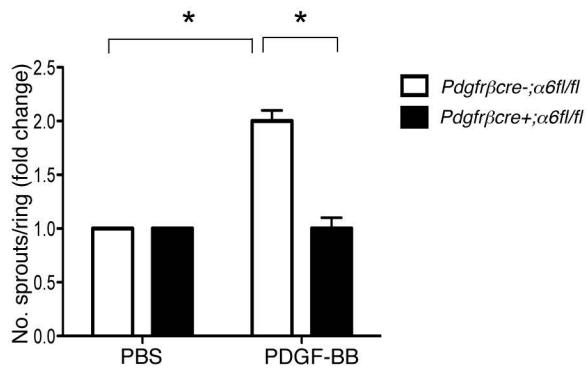
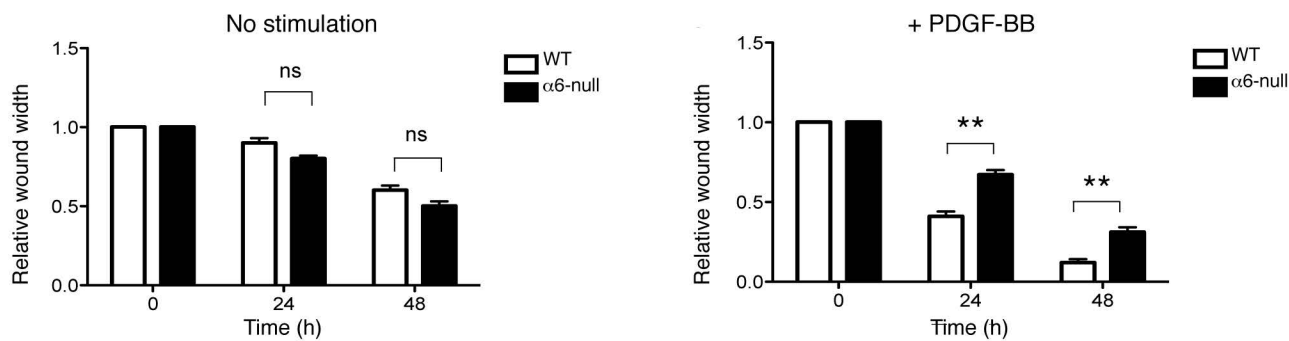


Figure 5. Reynolds *et al*

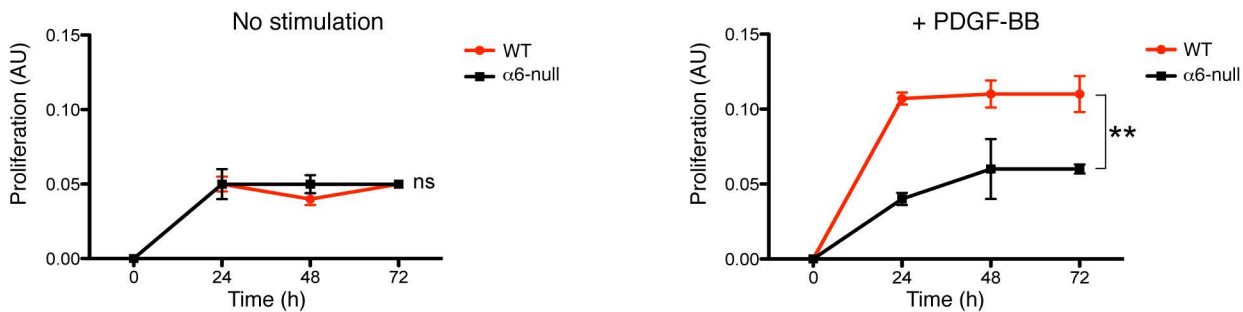
A



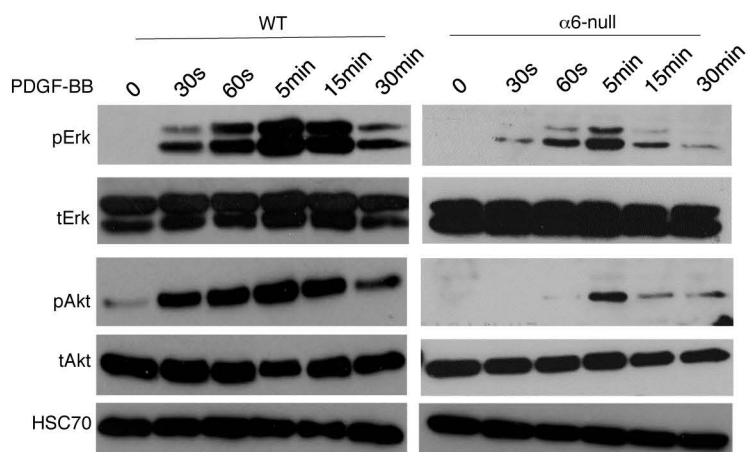
B



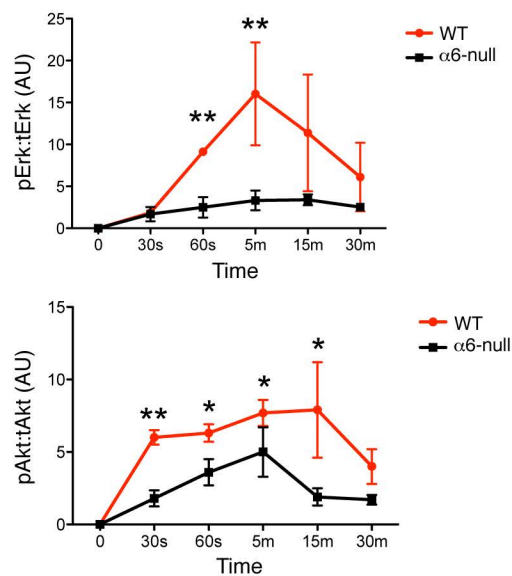
C



D



E



(GFAP) and Mac1 (fibroblast markers). Red graph = unstained cells, blue graph = stained cells. The results are shown as a histogram (left) and dot plot (right). *pdgfr β cre-; α 6fl/fl* mouse brain pericytes were also immunostained for NG2 (pericyte marker) and visualised by epifluorescence microscopy. **(B)** Primary mouse lung endothelial cells were stained for CD31 followed by FACS analysis and immunostained for endomucin and vimentin (expressed by ECs) and α -sma (fibroblast marker). **(C)** Primary mouse lung fibroblasts were immunostained for vimentin (positive marker for fibroblasts), NG2 and endomucin (negative markers for fibroblasts). Rat IgG was used as a negative control. **(D)** RPPA analysis of protein extracted from WT and α 6-null pericytes showed a significant reduction in many proteins in α 6-null pericytes. These included components of the mTOR signalling pathway – AKT, p70S6kinase, mTOR, pS6 ribosomal protein and 4E-BP1; this pathway is important for several cell functions including growth, migration, proliferation and angiogenesis and is known to be activated by integrins.